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Impacts of Land Cover Changes on Ecosystem Services Delivery in the Black Hills Ecoregion from 1950 to 2010

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IMPACTS OF LAND COVER CHANGES ON ECOSYSTEM SERVICES DELIVERY IN THE BLACK HILLS ECOREGION FROM 1950 TO 2010

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Geography degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidates are necessarily the conclusions of the major department.

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GLOSSARY AND LIST OF ABBREVIATIONS

AUM	Animal unit months (AUMs) in a grazing area (calculated by multiplying the number of animal units by the number of months of grazing) provide a useful indicator of the amount of forage consumed.
BHNF	Black Hills National Forest
CSP	Custer State Park
Drivers	Any natural or human-induced factor that directly or indirectly causes a change in ecosystems (Millennium Ecosystem Assessment 2005).
Ecosystem	A dynamic complex of plant, animal, and microorganism communities and their nonliving environment interacting as a functional unit (Millennium Ecosystem Assessment 2005).
Ecosystem function	An intrinsic ecosystem characteristic related to the set of conditions and processes whereby an ecosystem maintains its integrity (Millennium Ecosystem Assessment 2005).
Ecosystem Services (ES)	Benefits that humans recognize as obtained from ecosystems that support, directly or indirectly, their survival and quality of life. These include provisioning, regulating, and cultural services that directly benefit people, and the supporting services needed to maintain the direct services (Millennium Ecosystem Assessment 2005).
GIS	Geographic Information Systems
Impacts	The negative or positive effects on individuals, society, and/or environmental resources created by changes in variables (Hassan et al. 2005).
Indicator	A simple, measurable, and quantifiable characteristic responding in a known and communicable way to a changing environmental condition, to a changing ecological process or function, or to a changing element of biodiversity.
Land cover	The quantity and type of surface vegetation, water, and earth materials (*i.e.*, the biophysical state of the land) (Matlock and Morgan 2011, 90).
Landscape	A heterogeneous mosaic of habitat patches, physical conditions, or other spatially variable elements viewed at scales relevant to the organisms or processes under consideration (Vandewalle et al. 2009).
Land use	The human employment of the land including settlement, cultivation, pasture, rangeland, recreation, and so forth (Matlock and Morgan 2011,

	90).
MMBF	Millions of board feet of timber
NLCD	National Land Cover Database. A 16-class land cover classification scheme that has been applied consistently across the conterminous United States at a spatial resolution of 30 meters in 2001 and 2006.
Potential Production (PP)	The hypothetical maximum yield of selected optimized services provided by a certain land cover (derived from Burkhard et al. 2012).
Potential Supply (PS)	The hypothetical maximum yield of selected optimized services in a certain area or landscape (Burkhard et al. 2012).
RLCM	Rapid Land Cover Mapper.
Stakeholder	A person having a stake or interest in a biological or physical resource, ecosystem service, institution or social system, or someone who is or may be affected by a public policy (adapted from Millennium Ecosystem Assessment 2005).
Supply (of ES)	The capacity of a particular landscape to provide a specific bundle of ES within a given time period (Burkhard et al. 2012).
WCNP	Wind Cave National Park.

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ABSTRACT

IMPACTS OF LAND COVER CHANGES ON ECOSYSTEM SERVICES DELIVERY IN THE BLACK HILLS ECOREGION FROM 1950 TO 2010

SUZANNE COTILLON

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Environmental degradation generated by land use choices and human activities is the first driver of change in the provision of ecosystem goods and services. One of the challenges in ecosystem services research is to evaluate the contribution of each land cover unit to ecosystem services delivery while considering multiple services. In this thesis, I develop a framework to assess the capacity of many land covers to independently produce ecosystem services (*i.e.*, potential production) and the capacity of the whole landscape to deliver multiple services to the population (*i.e.*, potential supply). In the first part, this methodology is used to report on the change in ecosystem services delivery in the Black Hills ecoregion resulting from land cover modifications over a 60-year period. The trajectories of change in the Black Hills land cover are quantified using manual land cover mapping on aerial photographs from circa 1950 and circa 2010. In the second part, the same methodology is applied to the Black Hills National Forest, Custer State Park, and Wind Cave National park, in order to compare different management systems in the Black Hills and their implications for ecosystems services delivery over time. Although the trends of changes vary among the case studies following management directions and actions, most of the land cover conversions from 1950 and 2010 occurred on public land and affected ecosystem services delivery by the landscape. The three major net land cover changes were a loss of dense forest, a gain of medium and open forests, and a decrease in grassland/shrubland area. Even though the main drivers of change were not always human-induced, managers have been working to restore ecosystems, enhance their functionalities, and thus have been moving the landscape toward a higher level of ecosystems services delivery. By identifying the relationships between past and current land management, land cover changes and their drivers, and ecosystem services, this study contributes to a better understanding of land management results and their impacts upon Black Hills ecoregion sustainability and ecosystem services delivery.

Key words: Black Hills ecoregion; ecosystem services; score-based assessment; land use management; drivers; land cover changes; aerial photographs.

CHAPTER 1. INTRODUCTION

1.1. Problem Identification and Description

Land use change to provide food, fiber, timber, and space for settlement is one of the foundations of human civilization, but it can have both desirable and undesirable impacts on society (DeFries and Bounoua 2004, 139; Hermann, Schleifer, and Wrbka 2011). In the United-States, land use changes occurred dramatically fast after European settlement. Different mechanisms drove land transformations, such as the increase of population, improvements in technology, and the development of transportation (Marschner 1959, 1-10). Land use changes are not only related to economic development and other drivers but also to ecological characteristics of the land. Therefore, understanding the drivers of change and their relationship to the physical landscape is necessary to predict the future state of the land and the related impacts on the natural environment (DeFries, Foley, and Asner 2004).

Numerous studies underpin the assertion that land use is an important determinant of the state of the environment (Potschin 2009). Land use choices, such as deforestation, water diversion, urbanization, and cropland expansion, can alter ecosystem dynamics and biodiversity and adversely affect not only biodiversity but also a range of ecosystem services provided by the environment (Millennium Ecosystem Assessment 2005; Mitsuda and Ito 2011). *Ecosystem services* are the benefits that people can obtain from *ecosystem functions* (*i.e.* physical, chemical, and biological processes that contribute to the self-maintenance of an ecosystem). Some examples of ecosystem services are support of the food chain, harvesting of animals or plants, and the provision of clean water or scenic views.

The ecosystem services concept offers a way to deal with and alleviate the "dilemma" of land use change by incorporating effects on the environment into land management, policy, and economic decisions (Logsdon 2011, 3). It highlights the value of nature, emphasizes the contribution of the environment to human well-being, and helps define "reasonable" management plans. By understanding how human activities affect the ecosystem services we depend on, the negative feedback loops that are inevitably created when natural resources are used or consumed for human benefits could be reduced. Therefore, to maintain these benefits and encompass the economic, sociological, and environmental issues of an area, the land has to be managed as a coupled, multi-scale socio-ecological system (DeFries and Bounoua 2004).

1.2. Thesis Statement and Objectives

This study focuses on ecosystem services delivery related to land cover change in the Black Hills ecoregion in western South Dakota and eastern Wyoming. Following the federally sponsored Custer Expedition in 1874, a large immigration of European settlers exploited the region's natural resources and irrevocably changed the character, use, and occupation of the land. Considering the rapid settlement, and the dramatic use of natural resources, the increasing pressure on natural capital following land use changes likely modified the provision of ecosystem services over time. This study tests the hypothesis that **since 1950 land cover changes have resulted in the decrease of ecosystem services supplied by the Black Hills landscape.** Based on the design of a matrix relating each land cover class to a level of ecosystem service production, the developed methodology seeks to understand the dynamics of land cover contribution to ecosystem services delivery at the landscape scale. This research meets three main objectives: (1) quantify land cover change and associated drivers in the Black Hills since 1950; (2) identify the consequences of these changes on ecosystem services delivered by the landscape; and (3) analyze the results of past and current land management on ecosystem services delivery.

The research approach aims to develop a framework to answer the following questions:

- What is the potential production of the different land cover units of the study area?
- How do these potential productions vary with land management?
- To which extent did land cover conversions impact the total supply of ecosystem services by the landscape over time?

CHAPTER 2. LITERATURE REVIEW

2.1. The Unintended Consequences of Land Use Changes on Ecosystems

Land is used to meet a multiplicity of human needs and to serve diverse purposes. Anthropogenic land use change is the largest ecosystem pressure exerted by human beings on the landscape (Matlock and Morgan 2011). It includes both the direct conversion of the land surface (*i.e*. the land cover) and changes in land management to enhance productivity of natural resources (DeFries, Asner, and Houghton 2004, 3). For this reason, the analysis of land use transformations is essentially related to the analysis of the relationship between people and land (Intergovernmental Panel on Climate Change 2007).

Encouraged by many factors, such as technological or transportation improvements, human beings transform the physical environment, whether deliberately or inadvertently, and whether for better or worse (Clark and Mathews 1990, 139). The unmistakable trend in global land use, for all its unevenness through time and across space, has been the accelerating expansion of cropland at the expense of forest and rangeland. Total arable land has expanded by some 450 percent in the past three centuries. Other sources of impacts such as cutting trees for timber and fuel have contributed to a net loss of more than six million square kilometers of forest (Clark and Mathews 1990, 139-140). Foley et al. (2005) demonstrated that in the past 200 years, human beings have rearranged biomes across the planet, making agriculture (row crops, meadows, and grazing lands) the largest biome in the world whereas natural ecosystems are disappearing (Figure 1).

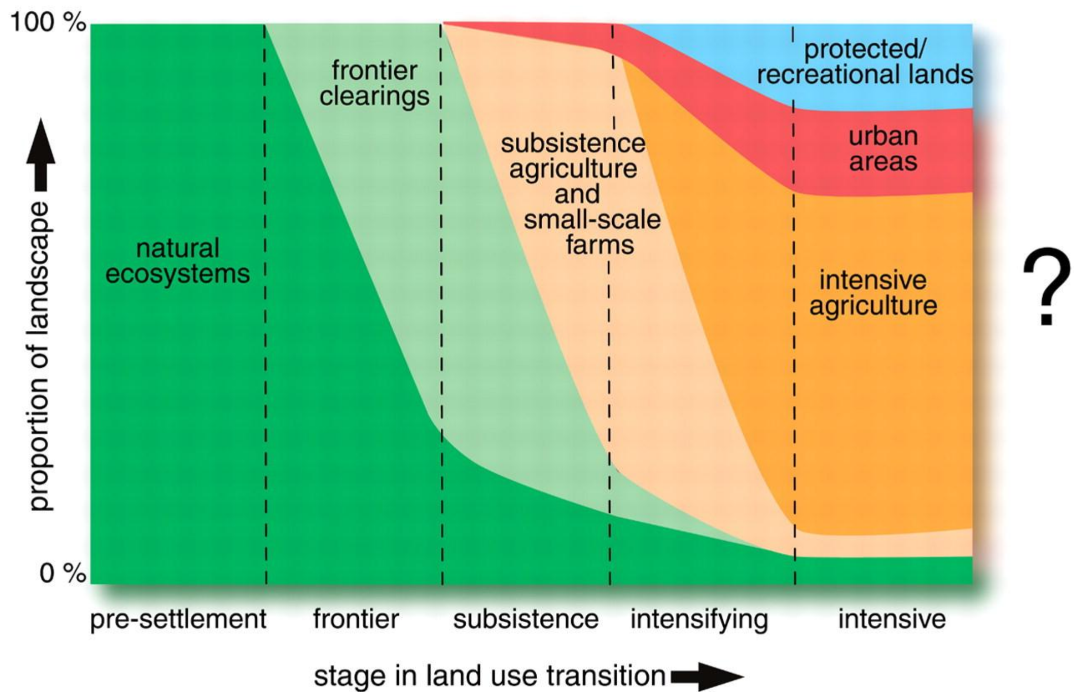

Figure 1. Model of land use transitions that may be experienced within a given region over time. Different parts of the world are in different transition stages, depending on their history, social and economic conditions, and ecological context (Foley et al. 2005, 571).

The fragmentation of ecosystems owing to changing land use, with attendant effects on biotic and biogeochemical functions, is another increasing concern central to the concern over the loss of biodiversity (Lindenmayer and Fischer 2006, 97-106; National Research Council 1999). Indeed, land cover conversions, as well as the partial removal of native vegetation cover, can alter ecological processes and have far-reaching and long-term effects that potentially compromise the basic functioning of ecosystems (DeFries, Asner, and Houghton 2004, vii, 1-9; DeFries, Foley, and Asner 2004, 251-255; Lindenmayer and Fischer 2006, 97).

Ecosystems are complex and dynamic, so their responses to environmental change may quite commonly be non-linear, hard to predict, and/or irreversible (Carpenter et al. 2009; DeFries, Asner, and Houghton 2004, 7). Ecosystem responses to land use change also vary in different ecological settings, even for the same type of land use transition (DeFries, Foley, and Asner 2004, 251). These unintended consequences vary according to the type of land use change, *e.g.*, forest clearing for agriculture, grassland conversion for grazing, or urban expansion, and they make ecosystem responses difficult to predict. As a result, an explicit quantification of land use changes is required to comprehend the multiple and cumulative impacts of human activities on ecosystems. Even if significant efforts have been made in developed countries to protect natural resources, ecosystems are still at risk and the link between ecosystem health and the benefits they provide to people need to be better understood (Molnar and Kubiszewski 2012).

Environmental degradation generated by land use choices is also the first cause of change in the provision of ecosystem goods and services (DeFries, Asner, and Houghton 2004, 1; Millennium Ecosystem Assessment 2005). According to the Millennium Ecosystem Assessment (2005), approximately 60 percent of global ecosystem services have been degraded or used unsustainably over the past 50 years. DeFries, Asner, and Houghton (2004) showed that the primary and overwhelming benefit to society from land use change is the appropriation of ecosystem goods - food, fiber, and timber - for human consumption. Land use changes increased the proportion of primary productivity for human use and decreased the proportion remaining to perform other ecosystem services such as the regulation of floods, climate, habitat for other species, and opportunities for recreation (DeFries, Asner, and Houghton 2004, 3; Raudsepp-Hearne, Peterson, and Bennett 2010, 5242).

To summarize the interrelations between environmental change and the provision of ecosystem services, a common structure can be sketched on the basis of the DPSIR (Drivers, Pressures, State, Impact, Response) approach developed by the Smeets and Weterings (1999) (Figure 2). The basic idea is that social, demographic, and economic developments in societies and the corresponding changes in motivations and lifestyles, result in changes to overall levels of consumption and production patterns – the *drivers* – and produce *pressures* on the environment. These pressures include developments in the release of substances (*e.g.*, emissions), physical and biological agents, the concrete utilization of resources, and the use of land by human activities. The corresponding inputs into an ecological system change the *state* of the environment, which refers to the quantitative and qualitative physical, biological, and chemical conditions in a defined area. Because of these pressures, there are *impacts* on natural and human systems that we understand as changes in the provision of ecosystem goods and services and in the socio-economic system. Finally, after these changes have been perceived, actions are carried out by society and governments to minimize the negative impacts imposed on the whole system (*response*).

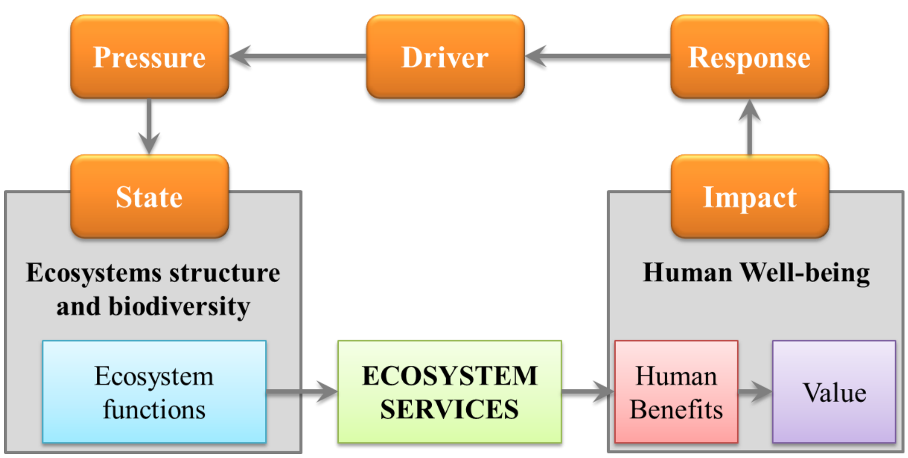

Figure 2. The 'ecosystem service cascade' embedded in the DSPIR framework (modified from Kandziora, Burkhard, and Müller 2013).

2.2. Understanding the Importance of Ecosystem Services

2.2.1. Definitions

The concept of ecosystem services is a promising approach to a better understanding of coupled natural and human systems because it communicates the links between ecosystems and human well-being (DeFries, Asner, and Houghton 2004, 1; Millennium Ecosystem Assessment 2005). Although the term "ecosystem services" was primarily introduced by Ehrlich and Ehrlich in 1981, the concept's origin dates to the late 1960s and 1970s, highlighting the societal value of nature's functions (Hermann, Schleifer, and Wrbka 2011, 5). Ecosystems services can be simply defined as a set of ecosystem functions[1] that are useful to humans. In other words, they are the benefits people obtain from ecosystems functioning and upon which our existence depends (Nicholson et al. 2009, 1140). It is clearly an anthropocentric concept: without a benefit, there is no service.

2.2.2. Ecosystem Services Typology

The Millennium Ecosystem Assessment (2005) classified ecosystem services into four groups: provisioning, regulating, cultural, and supporting (Table 1). Provisioning services are defined as services that provide a product that is used by humans, such as food, fiber, and fuel. Regulating services are described as services that regulate natural systems for the benefit of human life, such as climate and water purification. Cultural services are the least understood, but some would argue the most important services, as they are services that provide life-enhancing value, such as aesthetics and recreation.

[1] De Groot (1992) defined ecosystem functions as "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly." Functions can refer variously to the habitat, biological or system properties, or processes of ecosystems.

Lastly, the Millennium Ecosystem Assessment (2005) defined supporting services as ecosystem functions that support the previous three services, such as soil formation and primary production.

The classification of ecosystem services (*i.e.*, number and characteristics), however, is still debated among scientists (Hermann, Schleifer, and Wrbka 2011, 10-15). The full range of benefits reflecting human well-being from ecosystems must be represented in any effective typology of ecosystem services (Wenning and Apitz 2012, 236). To this aim, Potschin and Haines-Young (2011) and the UK National Ecosystem Assessment (UNEP World Conservation Monitoring Centre 2011) considered a new classification of ecosystem services, proposed for a Common International Classification of Ecosystem Services (CICES) in 2010, where the category 'supporting services' proposed by the Millennium Ecosystem Assessment (2005) is not considered because it is a synonym for ecological functions and processes that provide the other services. This classification is more relevant than the traditional classifications made by Costanza et al. (1997) or de Groot, Wilson, and Boumans (2002) and prevents double counting in ecosystem service quantification (Table 1). Wallace (2007) also proposed a new classification system as an alternative to the four categories of services defined by the MEA of provisioning, regulatory, cultural and supporting (Table 1). Wallace (2007, 239-240) argued that the concepts of means, such as ecosystem functions, and final ecosystem services, such as goods are often confused (Vihervaara, Rönkä, and Walls 2010). Ecosystem services should be described in terms of the structure and composition of ecosystem elements rather than ecosystem processes to avoid redundancy in ecosystem services classification and highlight benefits to humans. By defining four categories of

Table 1. Comparison of Costanza et al. (1997), Millennium Ecosystem Assessment (2005), Wallace (2007), and the Common International Classification of Ecosystem Services (2010) categories of ecosystem services (Logsdon 2011; Millennium Ecosystem Assessment 2005; Potschin and Haines-Young 2011).

Costanza et al. (1997)	**MEA Classification (2005)**	**Wallace Classification (2007)**	**Common International Classification of Ecosystem Services (2010)**
· Gas Regulation · Climate regulation · Disturbance regulation · Water regulation · Water supply · Erosion control and sediment retention · Soil formation · Nutrient cycling · Waste treatment · Pollination · Biological control · Refugia · Food production · Raw materials · Genetic resources · Recreation · Cultural	<u>(1) Provisioning:</u> Food Fiber Fuel…	<u>(1) Adequate Resources:</u> Food Oxygen Water Energy…	<u>(1) Provisioning:</u> Nutrition Materials Energy
	<u>(2) Regulating:</u> Climate regulation Disease regulation Natural hazard regulation Water purification Air quality regulation…	<u>(2) Protection from predators/disease/parasites</u> <u>(3) Benign physical and chemical environment:</u> Temperature Moisture Chemical…	<u>(2) Regulation and Maintenance:</u> Regulation of wastes Flow regulation Regulation of physical environment Regulation of biotic environment
	<u>(3) Cultural:</u> Recreation and ecotourism Spiritual and religious values Aesthetic values…	<u>(4) Socio-Cultural Fulfillment:</u> Spiritual/philosophical contentment Recreation/leisure Knowledge/education resources…	<u>(3) Cultural:</u> Symbolic Intellectual and Experiential
	<u>(4) Supporting:</u> Primary productivity Soil formation Nutrient cycling…	<u>Ecosystem Processes*:</u> Soil formation/retention Nutrient regulation Pollination…	

**Wallace (2007) and Potschin and Haines-Young (2011) do not call ecosystem processes services, but they do note that these support the different categories of services.*

"human values" (Table 1), Wallace's typology aims to provide a framework in which the consequences for human well-being of manipulating ecosystems may be assessed (Logsdon 2011, 11; Wallace 2007, 240). Costanza disproved Wallace's classification and explained that there are other important and useful ways to classify ecosystem services that are not captured in Wallace's typology (Costanza 2008). He mentioned two classification examples related (1) to spatial characteristics of their use (from global population to specific user) and (2) to ‘‘excludability/rivalness’’ status (*i.e.,* number of beneficiaries/competition between services delivery). He argued "all ecosystem services are in fact means to the end of human well-being; ecosystem processes can also be services (they are not mutually exclusive categories), and the same services can be both intermediate and final" (Costanza 2008, 351). To conclude the debate, Costanza showed that there is no good or wrong classification because of the complexity of ecosystem services, and emphasized the need for a consistent use of terminology in ecosystem services research. Ecosystem services classification should be adapted to the purpose and the site of the study.

2.3. Quantifying and Mapping the Capacity of Ecosystems to Provide Services

2.3.1. Mapping and visualizing ecosystem services

Costanza (2008) emphasized that ecosystem services are the products of places and thus situated the ecosystem services debate within a geographical framework. Indeed, quantifying and mapping supplies of ecosystem services is essential for continuous monitoring of such services to support decision-making. The mapping of ecosystem services has been listed as one-key element that is required in order to improve the recognition and implementation of ecosystem services into decision-making (Daily and Matson 2008). In recent years, geographic information systems (GIS) have become a powerful tool for mapping and assessing the provision of ecosystem services within a landscape. GIS can help land managers to visualize spatial and temporal patterns and changes in ecosystem services, and estimate the potential impacts from projected changes in land use or management or climatic conditions on the provision of these services

(Nemec and Raudsepp-Hearne 2013). Geographers are now interested in developing methods to quantify the provision and value of ecosystem services so this information can be incorporated into planning and decision-making at different scales and in different sectors. These methods, however, vary considerably in the scale and scope of the analysis as well as in the assessment approach of ecosystem goods and services production (Burkhard et al. 2009).

2.3.2. Quantifying approaches

2.3.2.1. The ecological production function approach

The relationship between land use/land cover and ecosystem services is conceptually apparent. As land use changes, processes on the land change, which impact ecosystems functioning and resulting services (Matlock and Morgan 2011, 37). Land use/land cover has been widely used as a proxy for ecosystems to derive regional scale indicators for ecosystem functions and highlight trends of land use influence on ecosystem services supply.

The earliest quantification method, which is still widely used by scientists today, estimates ecosystem services quantity from land use production functions from global to local scales (Costanza et al. 1997; Egoh et al. 2008; Naidoo et al. 2008; Petz et al. 2012; Willemen et al. 2010; Willemen et al. 2008). The ecological production function approach is used to represent the output of ecosystem services that are provided by an ecosystem (Tallis and Polasky 2009). Usually, this method uses the modeling of ecological functions for a single ecosystem service at a time. Finding appropriate indicators related to the specific service providing unit and exploring how functions and services are correlated with different landscape scenarios are still unresolved questions

(Hermann, Schleifer, and Wrbka 2011). For instance, the capacity of riparian areas to provide the service “water purification” will depend not only on the net primary production of the vegetation, which can be modeled and estimated, but also on the presence of contaminants in water, which can be related to its distance to arable land.

Indicators of ecosystem services are chosen and mapped in order to understand where ecosystem services are located on a landscape, to identify the location of ‘hotspots’ where high provision of individual or multiple ecosystem services occurs, and to better understand trade-offs and synergies among services (Egoh et al. 2008; Naidoo et al. 2008; Raudsepp-Hearne 2010; Willemen et al. 2010). At regional or local scales, a more data-driven method can be used. Function and service data are derived mainly from field observations, as well as census data, spatial policy documents, and biophysical data. Willemen et al. (2008) present a methodological framework to quantify landscape functions and to make their spatial variability explicit. They distinguish three different methods depending on the measurable function: (1) linking landscape functions to land cover or spatial policy data, (2) empirical predictions using spatial indicators, and (3) decision rules based on literature reviews (Willemen et al. 2008). The authors emphasize that whereas some ecosystem functions can be directly observed from the land-cover (*e.g.*, wood for timber production), other functions such as recreation cannot be directly observed or only partially delineated and thus require additional landscape data based on expert knowledge, literature reviews, or process models (Burkhard et al. 2009; de Groot et al. 2010).

Research teams have recently developed several programs to model multiple ecosystem services in a variety of systems. The most widely used software for mapping ecosystem services is InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) (Natural Capital Project 2011), which is an open-source GIS tool that has been created by several partners for estimating ecosystem service values using the ecological production function approach. Ecosystem processes and services that can be modeled by InVEST so far include wave energy, coastal vulnerability, coastal protection, marine fish aquaculture, marine aesthetic quality, fisheries and recreation, marine habitat, terrestrial biodiversity, carbon storage and sequestration, reservoir hydropower production, water purification/nutrient retention, sediment retention, timber production, and crop pollination. As stated before, the ecological production function approach requires considerable primary data, expertise, time, and funding to implement. It is not always possible to model the ecosystem services that are most relevant to a given decision in a specific location, if the ecological production functions are not developed or the data is not available for that location (Nemec and Raudsepp-Hearne 2013, 7). Tools such as InVEST will be critical for meeting the needs of decision-makers and researchers who do not have the resources to develop context-specific models for multiple ecosystem services. It is important, however, to make sure that the models are used appropriately and the information generated is credible and relevant. The quality of available data and having local expertise to parameterize and check models will also be limiting factors.

2.3.2.2. Score-based ecosystem services assessment

To get around limitations of the ecosystem services function approach, Burkhard et al. (2009) developed a more general methodology to evaluate capacities of different landscapes to provide ecosystem services. They created a matrix relating land cover types to ecosystem services. At the intersections of each coupled land cover/ecosystem services, different land cover types' capacities to provide the individual service were assessed on a scale consisting of: 0 = no relevant capacity, 1 = low relevant capacity, 2 = relevant capacity, 3 = medium relevant capacity, 4 = high relevant capacity and 5 = very high relevant capacity. These scores are based on expert evaluations (conceptual and from different case studies) and experience from different case studies in different European regions, and can be considered as hypotheses of possible capacities of ecosystem service. Naturally, there is a high dependence on the observer's experience, knowledge, and objectivity, which service supplies are supposed to be relevant, and how to value them. However, this relative 0–5 scale offers a way of evaluating alternatives to monetary accounting or value-transfer methods. The purpose of their study was to combine this assessment matrix with statistical data (from ecosystem services function analysis) to map the capacity of the landscape to provide ecosystem services, implement the concept of ecosystem services as a solution for human–environmental problems, and provide a better data base for the mapping of ecosystem services (Burkhard et al. 2012).

Ecosystem services have been quantified at different spatial and temporal scales, in relation to their supply or production, demand and consumption, and using an array of indicators or metrics. The quantification and mapping of ecosystem services mostly involves assigning indicators of ecosystem services to the different land use/cover types (Ayanu et al. 2012; Eigenbrod et al. 2010; Lautenbach et al. 2011). The accuracy of quantification of ecosystem services thus depends on the accuracy of the classification, the number of land use/cover classes, and the working scale. Ecosystem services indicators, however, are numerous and lead to many studies that are not comparable.

Recent studies, such as UNEP-WCMC (2011) and de Groot et al. (2010), examined the methodologies, metrics and data sources employed in delivering ecosystem service indicators, so as to summarize the state of ecosystem indicator research and to inform future indicator development. Scientists, however, struggle to quantify ecosystem services using consistent, comparable approaches (Nemec and Raudsepp-Hearne 2013).

2.4. Ecosystem Services valuation

After quantifying ecosystem services, their monetary value can be estimated. In the 1970s and 1980s, a growing number of authors started to frame ecological concerns in economic terms in order to stress societal dependence on natural ecosystems and raise interest in biodiversity conservation (Gómez-Baggethun et al. 2010, 1213). Economic valuation was often applied to assess the total value of services of a particular ecosystem or landscape at a given time. For instance, the value of water purification by wetlands would be the costs saved by avoiding cleaning the water and other maintenance costs (the demand-side aspect of the model). The economic value of a service is tightly related to the quantification method used in the study. When quantification and valuation data are not available, explicit value transfer becomes a useful method to assess ecosystems or landscapes. Values and other data from the original study site (*i.e.,* from the literature or previous case studies) are transferred to the designated policy site (Loomis 1993). This approach, however, also suffers from limitations, such as availability of data, strength of the data, and comparability between the source data and policy context (Troy and Wilson 2006). Whereas some ecosystem services are easily transferable because they are provided at large scales (*e.g.,* the avoided greenhouse gas costs of carbon sequestration), other local scale services may have limited transferability (*e.g.,* flood control values) (Hermann, Schleifer, and Wrbka 2011).

In ecosystem services research, the monetization of the "value" of ecosystem services is still an ongoing debate among ecologists and economists. Most ecologists and other natural scientists would avoid using the term "value", except perhaps in its common usage as a reference to the magnitude of a number – *e.g.,* "the value of a parameter or indicator" (Farber et al. 2006), because ecosystems are seen to have an "intrinsic value" that cannot be measured (Hermann, Schleifer, and Wrbka 2011). Economic valuation, however, cannot consider all services, and thus underestimates the provision of ecosystems services by the environment. Some non-market ecosystem services related to aesthetics or cultural values cannot be quantified by monetary values, yet these services should still be accounted for by decision makers and stakeholders (Nemec and Raudsepp-Hearne 2013, 11). In order to make well-informed management decisions, all costs and benefits should be taken into account, including ecological, socio-cultural, and economic values and perception (de Groot et al. 2010). Valuation of ecosystem services is limited by two main issues: (1) inability to capture a comprehensive picture of nature's societal value (especially non-use services), and (2) lack of information necessary to transfer monetary estimates of benefits across sites (Gomez-Baggethun and Ruiz-Perez 2011; Wainger and Mazzotta 2011, 728). Moreover, Gomez-Baggethun and Ruiz-Perez (2011) argue that economic framing of the environment and monetary valuation methods are not a neutral tool, but often serve as discursive framing for the commodification[2] of ecosystem services. Consequently, it is important to understand the limitations of

[2] The concept of commodification refers to the expansion of market trade to previously non-marketed areas, such as ecosystem goods and services (Gomez-Baggethun and Ruiz-Perez 2011, 619).

monetary estimates of nonmarket goods before relying too heavily on them. Economic valuation of the benefits ecosystems provide to people can be a useful tool, a concept to help decision-makers decide how to allocate natural resources, but it should not be the only approach to assess ecosystem services, because it is not necessarily an adequate indicator for resource management (Potschin and Haines-Young 2011; Seppelt et al. 2012, 146).

2.5. Current Challenges in Ecosystem Services Research

2.5.1. The Provision of Multiple Ecosystem Services

While research on ecosystem services has increased exponentially, it is unevenly distributed across the different ecosystem services categories (Molnar and Kubiszewski 2012, 46). Ecosystem service research has focused on certain services, ecosystem types, and geographical areas, while substantial knowledge gaps remain concerning several aspects (Vihervaara, Rönkä, and Walls 2010, 314). While some provisioning and regulating services (*e.g.*, food production and climate regulation) are highly studied, there is a lack of consideration for the interactions between social and ecological components of a system (Molnar and Kubiszewski 2012, 46; Nicholson et al. 2009, 1142). Tools for cultural ecosystem services assessment are inadequate; the only exception is ecotourism and recreation, which have a market value (Vihervaara, Rönkä, and Walls 2010, 317). The challenge with assessing cultural services is their intangibility and non-use values, which often renders them difficult to measure (Tengberg et al. 2012, 17). Nicholson et al. (2009) showed that there is an important need for research to develop metrics that allow one to measure, value, and track changes in the stocks and flows of all ecosystem services, even the ones that are non-quantifiable using traditional methods. A major research effort is now underway to quantify, estimate, and manage ecosystem services that may inform fundamental changes in society's approach to the environment. To provide a robust basis for decision-making, they recommend a process-based research approach that treats ecosystem service provision within the context of a linked social–ecological system that directly focuses on the causality from change in ecosystem services to human well-being.

2.5.2. Trade-offs Among Services

Although some strong tradeoffs occur between ecosystem services and particularly between provisioning and other services, addressing them poses another challenge for ecosystem service studies (Asner, DeFries, and Houghton 2004; Raudsepp-Hearne, Peterson, and Bennett 2010). These interactions among ecosystem services can occur when multiple services respond to the same driver of change or when interactions among the services themselves cause changes in one service to alter the provision of another (Busch et al. 2012, 2; Raudsepp-Hearne, Peterson, and Bennett 2010, 5242). Indeed, ecosystem management that attempts to maximize the production of one ecosystem service often results in substantial declines in the provision of other ecosystem services. For this reason, recent studies have called for increased attention to development of a theoretical understanding behind the relationships among ecosystem services (Bennett, Peterson, and Gordon 2009). Bennett, Peterson, and Gordon (2009) identify three reasons to be concerned with the relationships among ecosystem services: (1) trade-offs among services can create unwanted declines in some ecosystem services when management focuses on only one at a time (Diaz and Rosenberg 2008; Millennium Ecosystem Assessment 2005); (2) it appears that we may be able to alter these trade-offs by focusing on the ecosystem processes that link services (Pretty et al. 2006); and (3) ignoring dynamics may increase the risk of regime shifts in which sudden, unexpected, and often unwanted changes in ecosystem services are experienced (Gordon, Peterson, and Bennett 2008). In their study, Willemen et al. (2010) propose to assess landscape values by referring to the total potential provision of goods and services at multifunctional locations, which means that at one single location different ecosystem services are being provided. They show a trend that at multifunctional locations the total provided goods and services by the landscape are higher than at monofunctional sites. On the other hand, landscape functions (*i.e.*, ecosystem services) interact with each other in different ways. Some landscape functions are affected negatively by the presence of other functions while some other landscape functions seem to benefit from multifunctionality (Willemen et al. 2010, 72). This approach presents a further step in exploring the complex system of interacting landscape functions in relation to spatially heterogeneous multifunctional landscapes. Therefore, although there is evidence of relationships among ecosystem services, and that these need to be better understood to improve ecosystem management, the science that takes these relationships into account remains limited (Tallis et al. 2008).

2.6. Summary of the current literature and significance of the study

Human use of ecosystem services is expanding, commensurate with the growth in Earth's human population and expansion of consumption (Carpenter et al. 2009, 1306;

Matlock and Morgan 2011, 8-9; Millennium Ecosystem Assessment 2005). Unlike demand, the global supply of ecosystem services by the natural environment decreased during the past 50 years (Millennium Ecosystem Assessment 2005). Ecosystem services, considered as open-access resources, are underprovided and carelessly used (Lant, Ruhl, and Kraft 2008). The future capability of the natural environment to provide services is highly determined by modifications in socio-economic drivers, the resulting changes in land cover, and the vulnerability of ecosystem services to these changes, as well as biodiversity and climate conditions (Metzger et al. 2006, 69-70). Consequently, if the supply of ecosystem services declines, human societies' demands for ecosystem services might not be fulfilled anymore (Burkhard et al. 2012). Understanding the underlying processes leading to service provision, such as land cover change, is essential for predicting and managing variations in ecosystem services (Nicholson et al. 2009, 1140).

Nowadays, one of the challenges in ecosystem services research is to evaluate the contribution of different types of land cover to ecosystem services delivery while considering multiple services. Traditional methods, such as the ecological function approach, require many primary data on the composition, structure, and biophysical condition of ecosystems to quantify ecosystem functions provided by each ecosystem services. The availability of data is often an obstacle to the consideration of some services, such as erosion control, water purification, or cultural services. Thus, many studies do not encompass all the services provide by the landscape and ecosystem services are underestimated.

The purpose of this study is to develop a framework to (1) assess ecosystem services supply by the landscape and (2) evaluate the impact of land cover changes on this supply over time. The method used in this research is based on a scoring system from 0 to 3 to assess ecosystem services production for each land cover. It requires collaboration with local managers and knowledge of ecological processes, but does not necessitate as much primary data as the ecosystem function analysis approach. This approach not only contributes to an emerging literature that attempts to develop simpler general methods to estimate the capacity of landscapes to provide services, but also emphasizes the importance of multiple ecosystem services at broad geographic and temporal scales and the cooperation with local stakeholders (Burkhard et al. 2009; Ericksen 2012; Reyers et al. 2009).

CHAPTER 3. METHODS

3.1. Geographical Context

3.1.1. The ecoregion as a regional-scale ecosystem unit

Because of their cumulative effects, the impacts of human actions need to be evaluated at an appropriate scale. Most ecosystem research has been focused on local scales and missed the wider ecological consequences of some regional changes. According to Bailey and Ropes (1998), the regional approach is more useful for planning and management than the traditional scattered approach because all ecosystems operate within the context of larger ecosystems. At a regional scale, ecosystems are hierarchical with lower or smaller ones nesting or residing in higher-level ones. The landscape system has proprieties that cannot be observed from simply looking at the pieces (Bailey and Ropes 2002, 16-17). Some of the processes involved in a landscape composed of many ecosystems may be in addition to those in its separate components of ecosystems, such as interactions or feedbacks (Bailey and Ropes 2002, 20). In this perspective, the scale to study ecosystems must consider the relationships among soils, vegetation, materials, culture, climate, and topography of a particular region. In other words, the more appropriate scale to manage a landscape system corresponds well to the concept of ecological regions.

At the macroscale, ecological regions, or ecoregions, correspond to the large regions where climatic conditions are relatively uniform. At smaller scales, surface features break up the climatic regions into local climates and their associated vegetation types (Bailey and Ropes 2002, 33). Ecoregions are “areas of general similarity in ecosystem and in the type, quality, and quantity of environmental resources” (Omernik

1995, 51). Indeed, ecoregions define place in an ecological sense (Matlock and Morgan 2011, 81). They serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components (Matlock and Morgan 2011, 72). Olson et al. (2001), however, offered several cautions for using ecoregions. Because delineating ecoregions is somewhat arbitrary, ecoregion boundaries should be normally considered as wide transitional zones rather than sharp delineations.

Three ecoregions delineations are in common use today: Bailey and Ropes (1998), Omernik (1995), and the Olson et al. (2001) World Wildlife Fund (WWF) system. Omernik's ecoregions were developed by integrating watersheds with soil types and plant associations, and thus are more commonly used in ecosystem management. In the United-States, Omernik's system defines four levels of ecoregions that correspond to different levels of precision of vegetation characteristics and climate conditions. Local ecoregions (level III) are subdivided into areas called landscape mosaics (level IV), which in turn are subdivided into local ecosystems (Bailey and Ropes 2002, 33).

Ecoregions provide useful strata for communicating the status and trends of land-cover and land-use change across the nation because they are visible and they relate to the environmental characteristics scientists studying land cover/land use changes are trying to interpret (Gallant et al. 2004, 106). Ecoregions provide a geographically coherent context for land-cover and land use change, and they form a unit in terms of rates of change, types of change, and variability of change (Gallant et al. 2004; Omernik 1995).

3.1.2. The Black Hills ecoregion

A mountain range, such as the Black Hills in western South Dakota and eastern Wyoming, is a classic example of a landscape mosaic. In my research, I will use the level IV system of Omernik's ecoregions delineation because it provides very specific local characteristics that are critical for ecosystem studies. The Black Hills ecoregion is an outlier of the Middle Rockies ecoregion (level III), which is characterized by individual mountain ranges of mixed geology interspersed with high elevation coniferous forest and grassy parklands (US Environmental Protection Agency 2011). The Black Hills are spatially separated from the Middle Rockies, and form a unit distinct from the surrounding area: the Greats Plains (Figure 3). For this reason, they were given the appellation of "forested island in the plains" (Raventon 1994, 1-5). The Black Hills are composed of three distinct sub-ecoregions (level IV). The Black Hills Foothills and the Black Hills Plateau form concentric rings around the mountainous Core Highlands (Figure 3). Like other "islands," the Black Hills received plant communities and fauna from neighboring but larger lands (*i.e.,* Middle Rockies, Great Plains). Over time, the plant and animal species have evolved and adapted to suit their own peculiar insular conditions (Buttrick 1914, 223). The Black Hills ecosystems (or landscape mosaic) include range types that go from tall grass and mixed prairies to various forest types. The "island" ecological concept contributes to understanding the Black Hills ecosystem because species associated with ponderosa pine, white spruce, and hardwood communities could be more vulnerable to ecosystem changes (USDA 1996a).

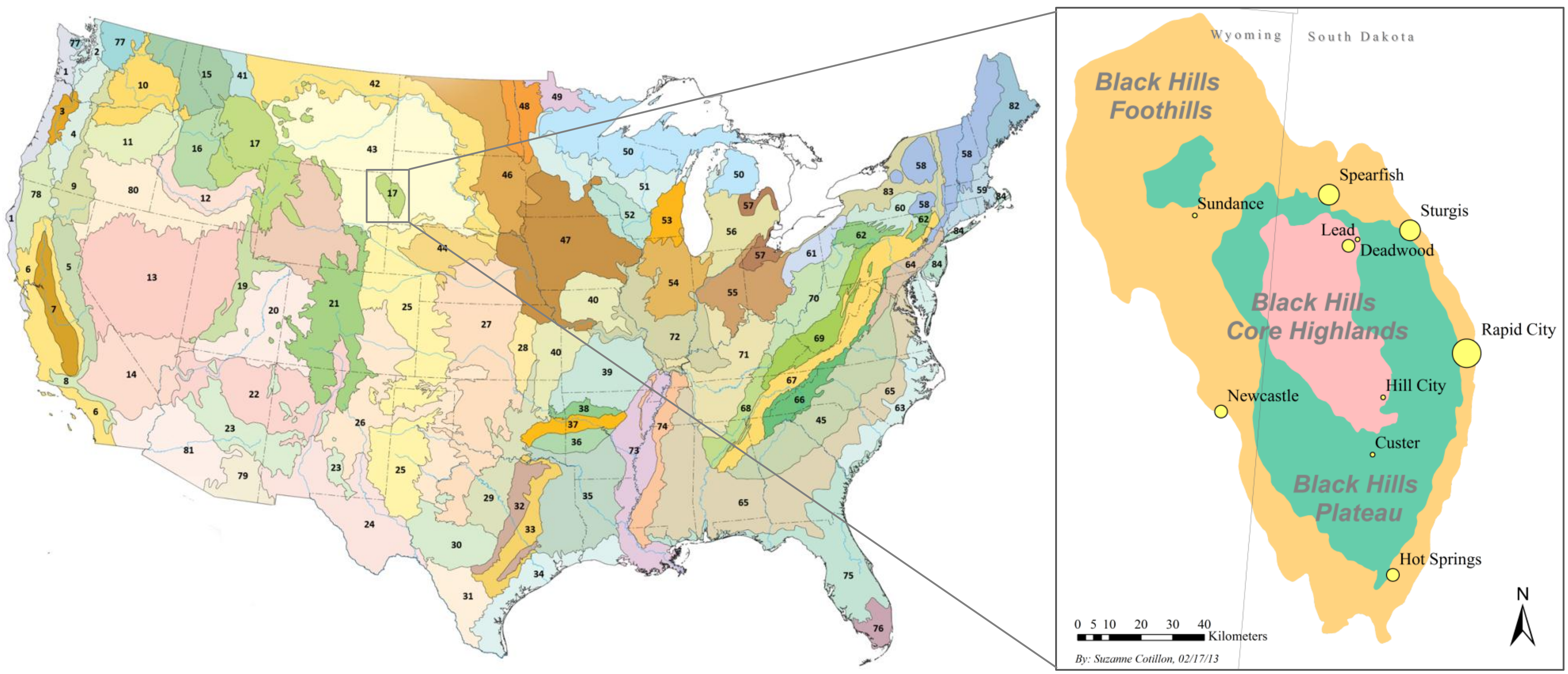

Figure 3. Ecoregions of the conterminous United States and enlargement of the the Black Hills ecoregion. Left: The Middle Rockies are represented in orange (17). Right: The Black Hills core highlands (pink), the Black Hills plateau (green), and the Black Hills foothills (orange) (US Environmental Protection Agency 2011; US Environmental Protection Agency 2012).

3.2. Background to the Study Area

3.2.1. Physical Characteristics

3.2.1.1. Physiography and Geology

The Black Hills ecoregion spans 200 km from north to south and 100 km from east to west. The total land base is nearly 1,214,000 hectares (3 million acres), with two-thirds of the area in southwest South Dakota and one-third in northeast Wyoming. The Black Hills ecoregion encompasses parts of seven counties, Crook and Weston in Wyoming, and Lawrence, Meade, Pennington, Custer, and Fall River in South Dakota (Figure 4). The Black Hills are a large, elliptically domed area uplifted during the Laramide Orogeny 60-65 million years ago. The peaks of the central part of the Black Hills presently are 900 to 1,200 meters (3,000 to 4,000 feet) above the surrounding plains. Harney Peak, with an altitude of 2,207 meters (7,242 feet), is the highest point in South Dakota (Figure 4). These central spires and peaks are carved from granite and other igneous and metamorphic rocks that form the core of the uplift. As a general rule, the closer a formation is to the center of the Black Hills, the older it is (Raventon 1994). The core is encircled by steeply dipping sedimentary deposits, comprising the Limestone Plateau and the "Red Valley" named because of its color due to red shale rocks. Surrounding the Red Valley is an outer hogback ridge formed by tilted layers of Dakota Sandstone, which are quite hard and resistant to erosion, and covered by ponderosa pine (Figure 5).

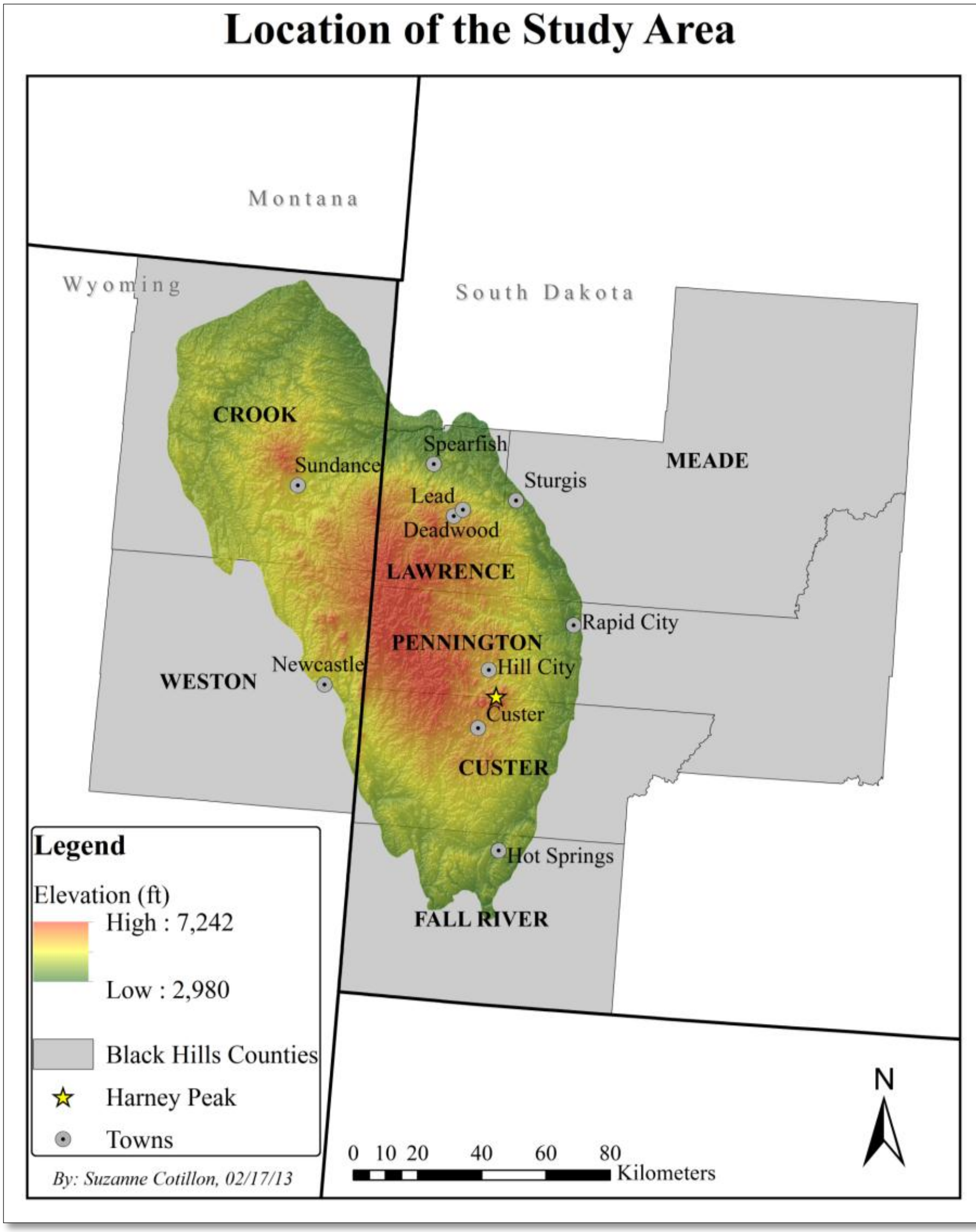

Figure 4. Location of the Black Hills of South Dakota and Wyoming, and counties encompassed.

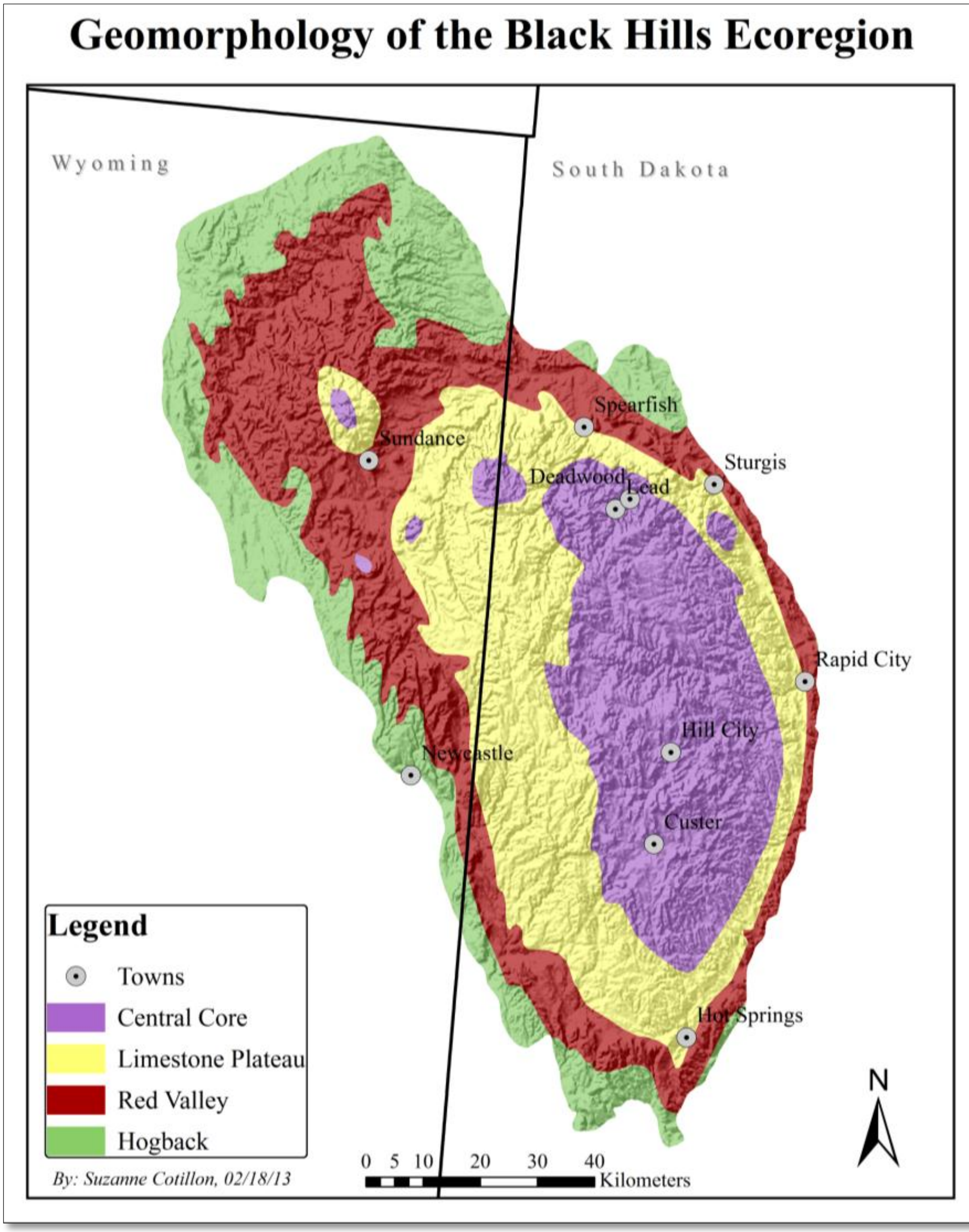

Figure 5. Geomorphic map of the Black Hills ecoregion modified from Schruben et al. (1994) and DeWitt (1989)[3].

[3] This map was created by regrouping polygons by geologic age and rock types. The central core is composed of igneous and metamorphic rocks from the early Proteozoic (2,250 to 1,000 Ma) as well as some more recent intrusions from the Paleogene (65 to 23 Ma). The Limestone Plateau is formed by lower Paleozoic (540 to 340 Ma) sedimentary rocks and the Red Valley by Triassic and Jurassic (250 to 145 Ma). The Hogback comprised sedimentary rocks from the Cretaceous (145 to 66 Ma).

3.2.1.2. Climate

The climate of the Black Hills differs from the surrounding plains because of the influence of the regional uplift. The Black Hills microclimate is a continental type, characterized by low precipitation amounts, hot summers, cold winters, and extreme variations in both precipitation and temperature (USDA 1996a). The climate of the area can be severe, and the weather patterns are erratic. The increased elevation results in an orographically induced microclimate that increases precipitation and decreases temperatures at the higher elevations (*Figure 6*). The precipitation patterns in the Black Hills differ along elevational and latitudal gradients (Shepperd and Battaglia 2002). The area can be divided into two separate climatic zones, the "Northern Hills" and the "Southern Hills." The Northern Hills zone is typically cooler, especially during the summer, and it has heavier snowfalls and more thunderstorms with resultant higher annual precipitation (82 centimeters in the Deadwood-Lead area) (USDA 1996a). In the Black Hills ecoregion, the average annual precipitation is 48 centimeters with about 92 percent of this total returned to the atmosphere via evapotranspiration. About 3.5 percent of annual precipitation recharges groundwater aquifers in the area and about 4.5 percent of the annual precipitation becomes surface runoff (USDA 1996a).

Mean annual temperature is also influenced by latitude and elevation. Stations in the northern Black Hills are generally cooler than those at similar elevations in the southern Black Hills. As a result, the growing season in the Black Hills ranges from 154 days at Rapid City to a very short season of 100 days in the higher northern locations (Froiland 1990, 35; Orr 1975).

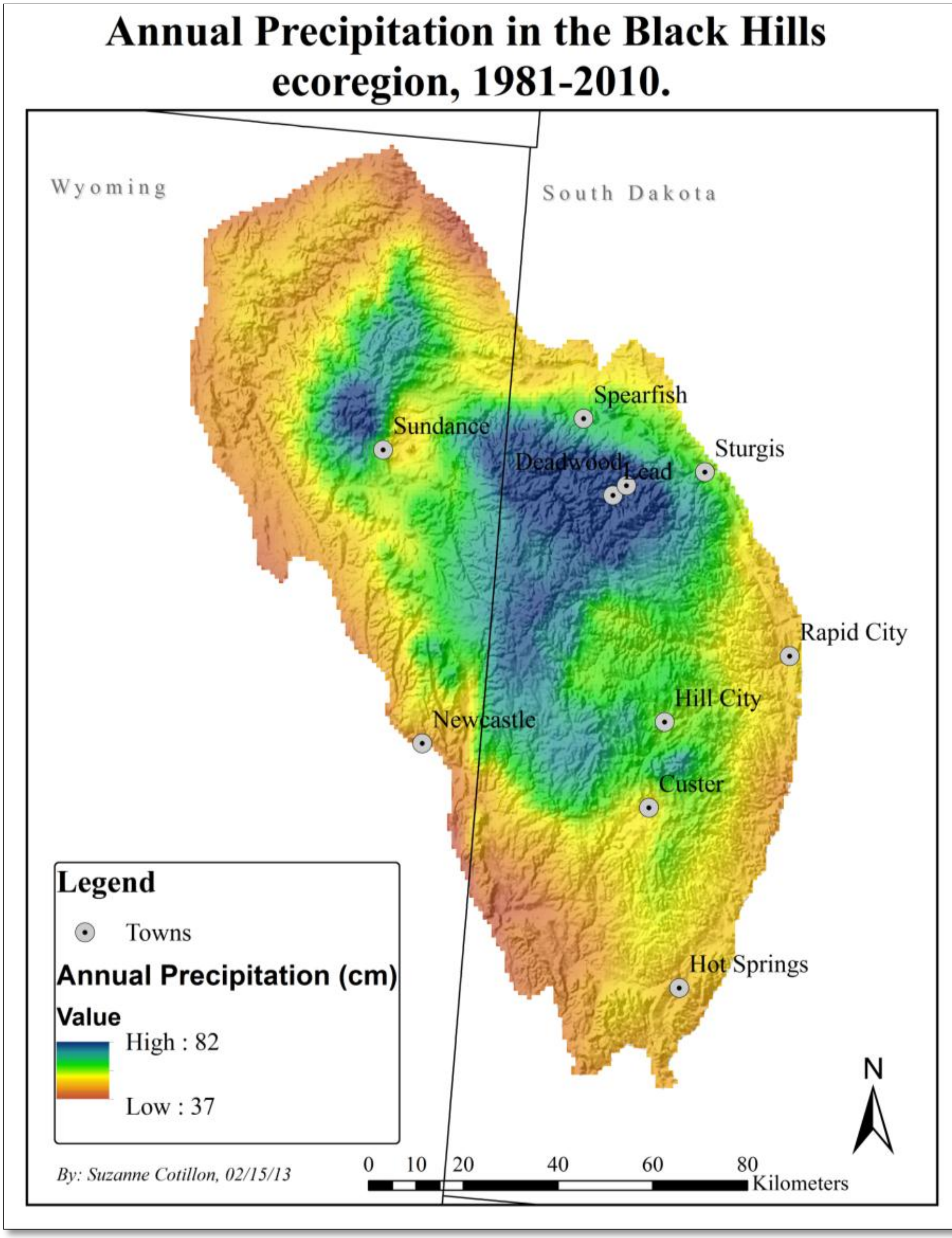

Figure 6. Mean annual precipitation in the Black Hills ecoregion from 1981 to 2010 (data from PRISM Climate Group 2012).

3.2.1.3. Hydrology

Surface and groundwater interactions in the Black Hills are very complex. The hydrology of the Black Hills is largely dictated by both the geology and topography. Numerous headwater springs radiating from the divide formed by Limestone Plateau, where more precipitation and less evapotranspiration result in more water being available for spring flow and stream flow, provide base flow for many streams (Figure 7). Much of this water, however, is absorbed as the streams cross over limestone and sandstone exposures, that are porous and permeable, and thus allow stream water to enter into bedrock aquifers (Driscoll et al. 2002). The more permeable of these sedimentary rocks contain major aquifers that are able to store and transmit large quantities of water that are used extensively for water supplies within and beyond the study area.

Karst features of the Limestone Plateau, including sinkholes, collapse features, solution cavities, and caves, are responsible for the aquifer's capacity to accept recharge from streamflow (Carter and Driscoll 2006). Whereas, there are no naturally occurring lakes in the Black Hills, there are numerous groundwater-dependent ecosystems such as Jewel Cave and Wind Cave in the limestone section.

The Black Hills vegetation also greatly influences the regional hydrology. Primarily composed of ponderosa pine with smaller, scattered hardwood forests and grassland areas, the Black Hills forest significantly reduces available surface and soil moisture because of transpiration and evaporation of intercepted precipitation (Fontaine et al. 2001). In the Black Hills area, where potential evaporation generally exceeds precipitation, most water is eventually returned to the atmosphere through evapo-transpiration.

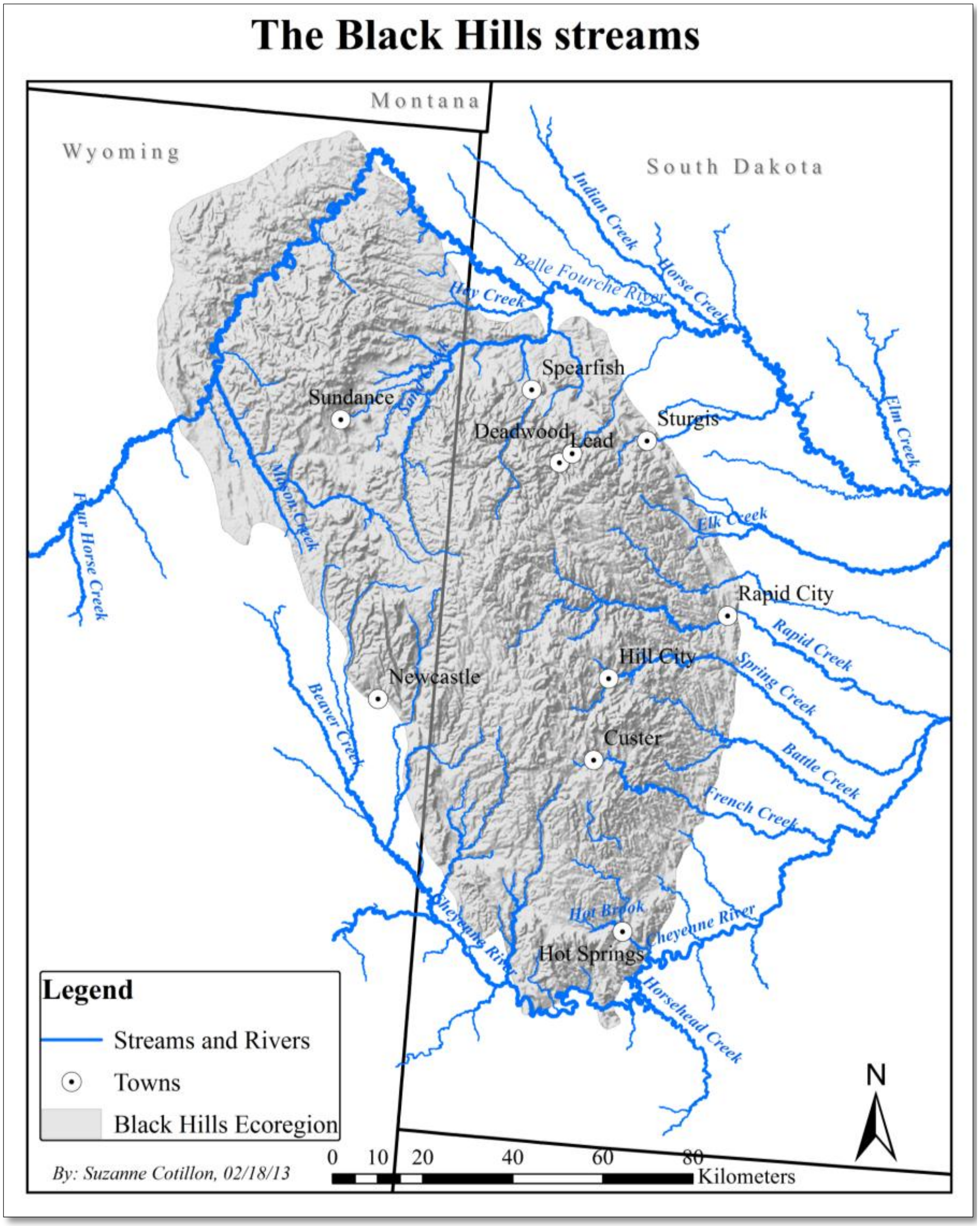

Figure 7. Main streams and rivers of the Black Hills ecoregion (data from Black Hills National Forest 2000).

3.2.1.1. Vegetation

The climatic variations are reflected in the vegetation patterns of the Black Hills. In the hierarchical ecological mapping system of ecosystems used by the Forest Service, the Black Hills are in a "dry-domain, Temperate-Steppe regime of the Mountain Division" (USDA Forest Service 1996). The Black Hills ecosystem (or landscape mosaic) includes range types that go from the tall grass and mixed prairies (covered above) to various forest types (Larson and Johnson 1999).

There are four distinct vegetative complexes that characterize the Black Hills: (1) the Rocky Mountain Coniferous Forest complex dominated by ponderosa pine (*Pinus ponderosa*), which covers 95 percent of the Black Hills forest, (2) the Northern coniferous Forest Complex consisting of white spruce (*Picea glauca*) and associated species, (3) the Grassland Complex of the northern Great Plains, and (4) the Deciduous Forest Complex (Table 2 and Figure 8) (Froiland 1990). Black Hills' forests are dependent upon both natural and anthropogenic disturbance processes. The Black Hills forest often experiences wild fire, as well as large infestations by pine beetles. As an ecotone with various communities, the Black Hills functions as a place for the intermingling of species. The Black Hills also show considerable ecological diversity because of variations in temperature, moisture, and evaporation/transpiration gradients (Parrish et al. 1996). Because of this diversity, some observers have called the Black Hills one of the Nation's greatest natural resources (USDA 1996a).

Table 2. Description of the dominant species and characteristics of the Black Hills vegetation (Froiland 1990; Larson and Johnson 1999).

VEGETATIVE COMPLEXES	DOMINANT SPECIES	LOCATION IN THE BLACK HILLS	COMMENTS
Rocky Mountains Coniferous Forest	Ponderosa pine (*Pinus ponderosa*)	Majority of the forested area	Very tolerant of dry, hot growing conditions. Environmental and commercial importance.
	Rocky Mountain juniper (*Juniperus scopulorum*)	Mostly at lower elevation, often in areas transitional between ponderosa pine and prairie.	Dry habitat. Commercial value for timber.
Northern coniferous forest Complex	White spruce or Black Hills spruce (*Picea glauca*)	Locally dense forests in the northern Hills at mid-to-high elevation and exists as far south as the Custer State Park area and the Harney range.	South Dakota's state tree. Typically found on the north slopes and in moist situations.
Deciduous Complex	Mixture of bur oak (*Quercus macrocarpa*), American elm (*Ulmus americana L.*), green ash (*Fraxinus pennsylvanica*), box elder (*Acer negundo L.*) and eastern hop-horn-beam (*Ostrya virginiana*).	Northern slopes of the Hills (North of Deadwood and Southwest of Spearfish).	Along streams and meadow edges at lower elevations, progressing upstream from the adjacent plains.
	Cottonwood (*Populus deltoides*) Peach-leaved willow (*Salix amygdaloides*)	In the Plains and lower foothills	Streamside trees.
	Quaking aspen (*Populus tremuloides),* paper birch (*Betula papyrifera*)	Higher elevations	
Grasslands Complex	Western wheatgrass (*Agropyron smithii*), needle and thread (*Stipa comate)* green needlegrass (*Stipa viridula*), prairie junegrass (*Koeleria pyramidata*), side-oats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis*), and buffalo grass (*Buchloe dactyloides*).	Dominant vegetation surrounding hills but is present elsewhere.	Often as a transition grassland following forest fires.

Figure 8. a) View of the northern Black Hills foothills with deciduous trees (aspen at the front), and ponderosa pine forest (Rocky Mountains Coniferous Forest) associated with grasslands, cropland, and an urban area. b) Overall view of the Black Hills in the Harney Peak area. Notice the ponderosa pine forest (Rocky Mountains Coniferous Forest) with the Pre-Cambrian uplifted granite domes in the central area. (Pictures took in 2010).

3.2.2. History

The Black Hills region has had a complex and changing history of human occupation. American Indian occupation extends back thousands of years (USDA 1996a). For Sioux (Dakota) Indians, the Black Hills were known as “Paha Sapa,” meaning “hills that are black". The tribes used the Black Hills for hunting, gathering edible, medicinal and “sacred” plants, cutting poles for tepees and lodges, and holding social and spiritual ceremonies (USDA 1996a).

The Black Hills were part of the Louisiana Purchase in 1803 but were not explored by Europeans before 1823. The following invasion of the Black Hills by prospectors, travelers, and settlers led to a series of disputes and military engagements that generated animosity between Indians and Europeans settlers (Progulske and Illingworth 1974). These hostilities ended with the 1868 Fort Laramie Treaty, which created the Great Sioux Reservation, and affirmed that the Black Hills was Sioux land, closed to white settlers.

In 1874, however, the federal government sent the Custer Black Hills Expedition into the region to gather information about the terrain and resources (O'Harra 1913; Progulske and Illingworth 1974), but especially to find out whether persistent rumors of gold in the Black Hills were true. This expedition, which was stimulated by the demand for natural resources such as timber and minerals, was in direct violation of the 1868 Laramie Treaty (Rezatto and Goodson 1989). The expedition confirmed of the presence of gold and the Black Hills were opened to European settlement and an ensuing “Gold Rush.” At this time, there were no controls on who came to the Hills or how they could use the land. New industries, such as lumbering, agriculture, transportation, and recreation developed but all centered on mining. Gold, timber, and grazing land were open-access resources, used by all who wanted them without regard to their continued sustainability (Geores 1996). From the 1870s to the early 1900s, Black Hills settlers relentlessly exploited the land, drastically affected the natural environment of the Black Hills, and undeniably modified the landscape.

Numerous roads have been built to serve logging, mining, or other utilitarian uses and made the Black Hills one of the most accessible national forests (*Figure 9*). Indeed, according to a study of the U.S. Forest Service, 64 percent of the forested area on the Black Hills is less than one kilometer from an improved road; 21 percent is between 1and 1.5 kilometers; 14 percent is between 1.5 and 5 kilometers; while only 1 percent is between 5 and 8 kilometers (DeBlander 2002). These roads, and associated human impacts, modified the Black Hills environment and changed accessibility, which led to additional anthropogenic changes. Indeed, interactions between the natural environment and human-caused processes altered the fire regime, hydrology, grazing patterns, and insect infestations in the landscape, and changed the structure of the initial ponderosa pine forest. Recent literature suggests negative impacts from these consequences on ecosystems functions, and questions the results on ecosystem services provided by the remaining natural environment (Campbell and Brown 2012; Hall, Marriott, and Perot 2002; Phillips and Randolph 1998).

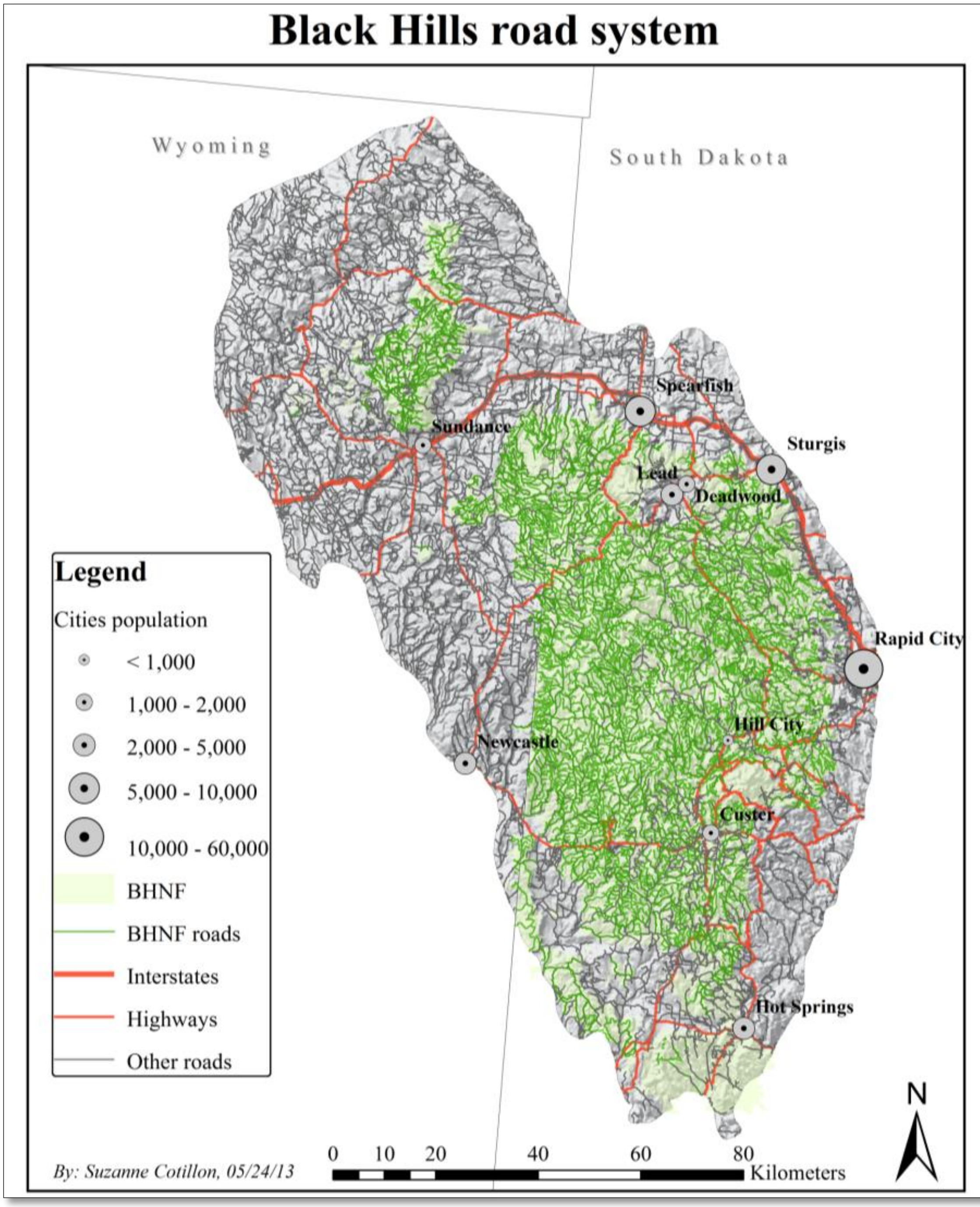

Figure 9. Road system in the Black Hills ecoregion. The highways and interstates are in red, the BHNF roads are in green, and the other main roads are in dark grey .

3.2.3. Current Land Ownership and Management

The current ownership of the Black Hills ecoregion shows the importance of the federal government in the area (Figure 10). Federal lands represent 40 percent of the ecoregion and are primarily managed by the USDA Forest Service (36.1 percent of ecoregion), National Park Service (1.1 percent), and Bureau of Land Management (1.8 percent). The Bureau of Reclamation and Army Corps of Engineers also manage small amounts of the ecoregion (less than 0.5%). The remaining land is in state ownership (5.6 percent of the ecoregion), private ownership (54.5 percent of the ecoregion) — mostly characterized by large ranches or small residential lots, or non-governmental organizations such as The Nature Conservancy, which manages 7,840 hectares of land (*i.e.*, 19,370 acres or 0.6 percent of the ecoregion) in the ecoregion (Hall, Marriott, and Perot 2002). The impacts of these different land management systems on ecosystem services will be further analyzed in three case studies: the Black Hills National Forest, Wind Cave National Park, and Custer State Park.

3.2.1. Summary: Why study the Black Hills?

The Black Hills ecoregion offers several unique opportunities for the study of interactions between land cover changes and ecosystem services delivery. Its geomorphology and biogeography provides a diverse landscape that can be easily classified by land cover types and produces a wide range of ecosystem services. Indeed, this "Island in the Plains" supports a biologically and culturally unique environment that for generations, has provided clean water, clean air, abundant game, wilderness, spirituality, inspiration, recreation, and a wealth of other values. The Black Hills

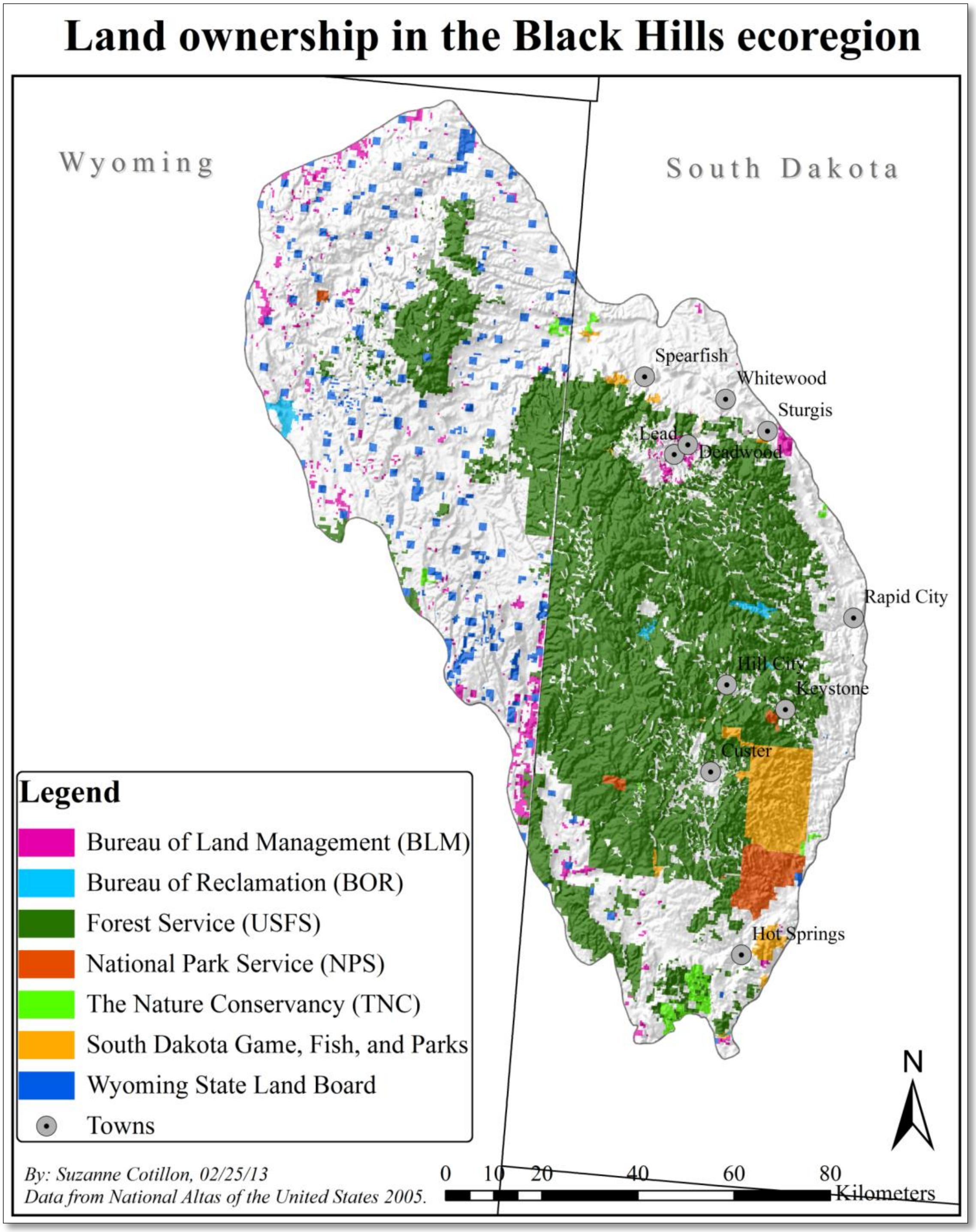

Figure 10. Ownership of the Black Hills ecoregion (National Atlas of the United States 2005). Areas in white are privately owned.

National Forest serves national interests in many ways, but it provides most dramatically to those communities that are located in or near the Forest. The richness of its resources made the Black Hills a land of multiple-uses that has not only a great economic significance, but also a great cultural significance.

3.3. Pilot Study

Because change is rare, detecting change can be a difficult task at a regional scale. The uncertainty of results may be an obstacle to establishing an appropriate methodology. To develop a reliable methodology, I undertook a pilot study using the National Land Cover Database (NLCD) from 2001 and 2006 as an alternative source of data to analyze land cover change in the Black Hills (Fry et al. 2011). These data were acquired from the federal mutli-resolution land characteristics consortium (MRLC) (http://www.mrlc.gov/finddata.php) and analyzed using ArcGIS. For both years, the study area was delineated and reclassified to nine land cover classes. The land cover classes considered with NLCD were forest, grassland, shrubland, developed land, barren, wetland, cropland, pasture, and open water. The results of this pilot study were used to run statistical analysis and determine the appropriate number of samples to evaluate land cover change in the Black Hills ecoregion (*cf*. 3.5.1.).

Even though the land cover classification and the time periods were different from my thesis work, this pilot study allowed me to predict some results, develop an adequate methodology, and improve my data analyses.

3.4. Data Collection

3.4.1. Aerial Photographs

The principal source of data is aerial photographs collected from the USGS Earth Explorer (http://earthexplorer.usgs.gov):

- 1950s: high resolution USGS Archives (1948-1958) and Army Map Service (1953) between 0.4 and 1.8 meter resolution (only 4 percent of the samples have a resolution higher than 1 meter);
- 2010s: USDA National Agriculture Imagery Program (NAIP) by county (2008-2010), 1-meter resolution.

Although aerial photographs are ideal for mapping small ecosystems and fine-scale landscape features, the various sources of images required a different strategy to pre-process each dataset, which can be time-consuming, and an obstacle to a constant data analysis method (Morgan, Gergel, and Coops 2010). Historical images from 1950s associated with my sample blocks were collected from USGS Archives with the collaboration of Ryan Longhenry from USGS-EROS. Most of the images (165 aerial photographs) had to be manually georeferenced and rectified in ArcGIS. I also collected the resolution and the date of acquisition for each image. Most of the images were acquired within a two-year period (1952-1954) but some were only available for 1948 or 1958 (Figure 11).

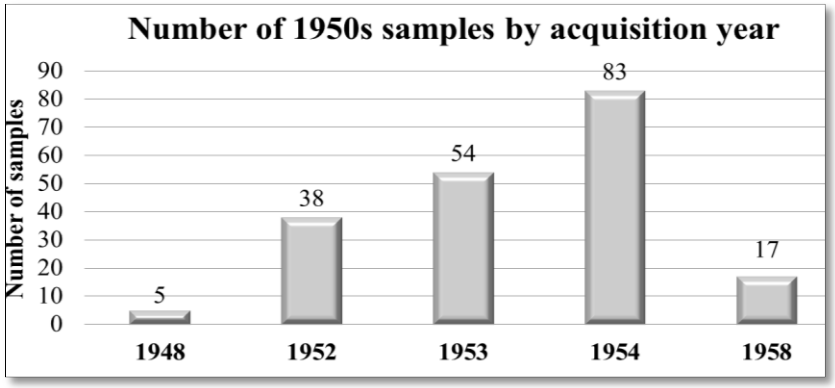

Figure 11. Number of aerial photographs used for 1950s analysis by year of acquisition.

3.4.2. Documents

To support data interpretation, I collected secondary data (*i.e.,* expedition diaries and reports, USDA Forest Service reports, scientific literature on the Black Hills, and so forth). I reviewed literature on ecosystem services and land use issues in order to acquire a working knowledge and to become aware of the most recent research and methods.

Moreover, I used semester research projects to provide additional background to my thesis. In the fall 2011, I wrote a research paper on the "Historical Geography of Land Changes in the Black Hills" which helped me understand the spatial and temporal evolution of land uses in the ecoregion since European settlement and the consequences on the current ecosystems. Then during the fall 2012, I studied "The Federal impact on land use management in the Black Hills" to understand the origins of the federal ownership in the Black Hills and the consequences of federal land ownership on the current land management system of the ecoregion. These projects have been beneficial to understanding and identifying the land management issues in the Black Hills.

3.4.3. Interviews

To study land use issues, it is important to consider stakeholders' points of view. During fieldwork, I interviewed managers from the Black Hills National Forest, Custer State Park, Wind Cave National Park, and the Rocky Mountain Research Station who provided me with information on their management policies and helped validate my results (Table 3). I provided my methodology to each manager and asked them to validate the indices of production P_n^i (0=null, 1=low, 2=medium, 3=high) assigned to each coupled land cover *i*/ecosystem service *n*, which is used to estimate the contribution of each land cover to ecosystem service production (*cf.* 3.6.2.). Finally, the final matrix of indices of production for each management area (*i.e.*, Black Hills National Forest, Custer State Park, and Wind Cave National Park) was adjusted following managers' comments.

Table 3. Names and titles of the individuals interviewed for each case study.

Case Study	Interviewees
Black Hills National Forest	**Rick Hudson –** Recreation Program Manager **Blaine Cook** – Forest Silviculturist **Sarah Erickson** – GIS specialist **Michael Hilton –** Forest Archeologist
Rocky Mountain Research Station (BHNF)	**Mike Battaglia** – Research Forester, Scientist in charge of Black Hills Experimental Forest
Custer State Park	**Craig Pugsley –** Visitor Services Coordinator **Gary Brundige –** Resource Program Manager
Wind Cave National Park	**Greg Schroeder –** Chief of Resource Management **Beth Burkhart** – Botanist

3.5. Land Cover Analysis

3.5.1. Ecoregion Stratified Sampling

The NLCD pilot study (*cf.* 3.3.) showed that the three ecoregion zones were not homogeneous in terms of land cover changes. Thus, a stratified sampling was used to sample the Black Hills ecoregions following the boundaries of each concentric zone. The purpose was to estimate change by sampling a portion of each zone. To be relevant, however, the sample size must capture the spatial configuration within and among land cover types (*i.e.,* ecosystem scale). I used the NLCD data to determine the sample size required to capture significant change in the Black Hills. A statistical analysis (One-Sample T-Test) was used to compare the mean land cover change value in the sampled area to the land cover change value of each ecoregion (total blocks population) using the NLCD 2001-2006 data (Figure 12). The number of samples in each ecoregion was adjusted until the null hypothesis was accepted (Appendix A). Through investigation of various block sizes, it was determined that 195 sample blocks (45 in the Black Hills core, 95 in the Black Hills plateau, and 90 in the Black Hills foothills) of 2.5 km by 2.5 km were large enough to adequately capture this information and yet small enough to allow for relatively rapid analysis and processing. The total sampled area represents 8.7 percent of the whole ecoregion.

3.5.1. Land Cover Classification

The land cover classification used in this study contains eleven classes: open forest (canopy cover < 25%), medium forest (25 %< canopy cover < 75%), dense forest (canopy cover > 75%), grassland/shrubland, cropland, natural barren land, quarries/ mines, developed land, open water, disturbed area[4], and riparian area (Appendix B). Each sample block was classified with ArcGIS using the RLCM tool developed by USGS EROS. The RLCM tool, which stands for Rapid Land Cover Mapper, is a vector/raster hybrid approach to land cover mapping. It lends itself to both multiple resolutions and

[4] On the black and white 1950s imagery, the classification of the disturbed areas was not possible because the Mountain Pine beetle infestations are not visible without colors. Therefore, this class is not considered in the ecosystem services analysis.

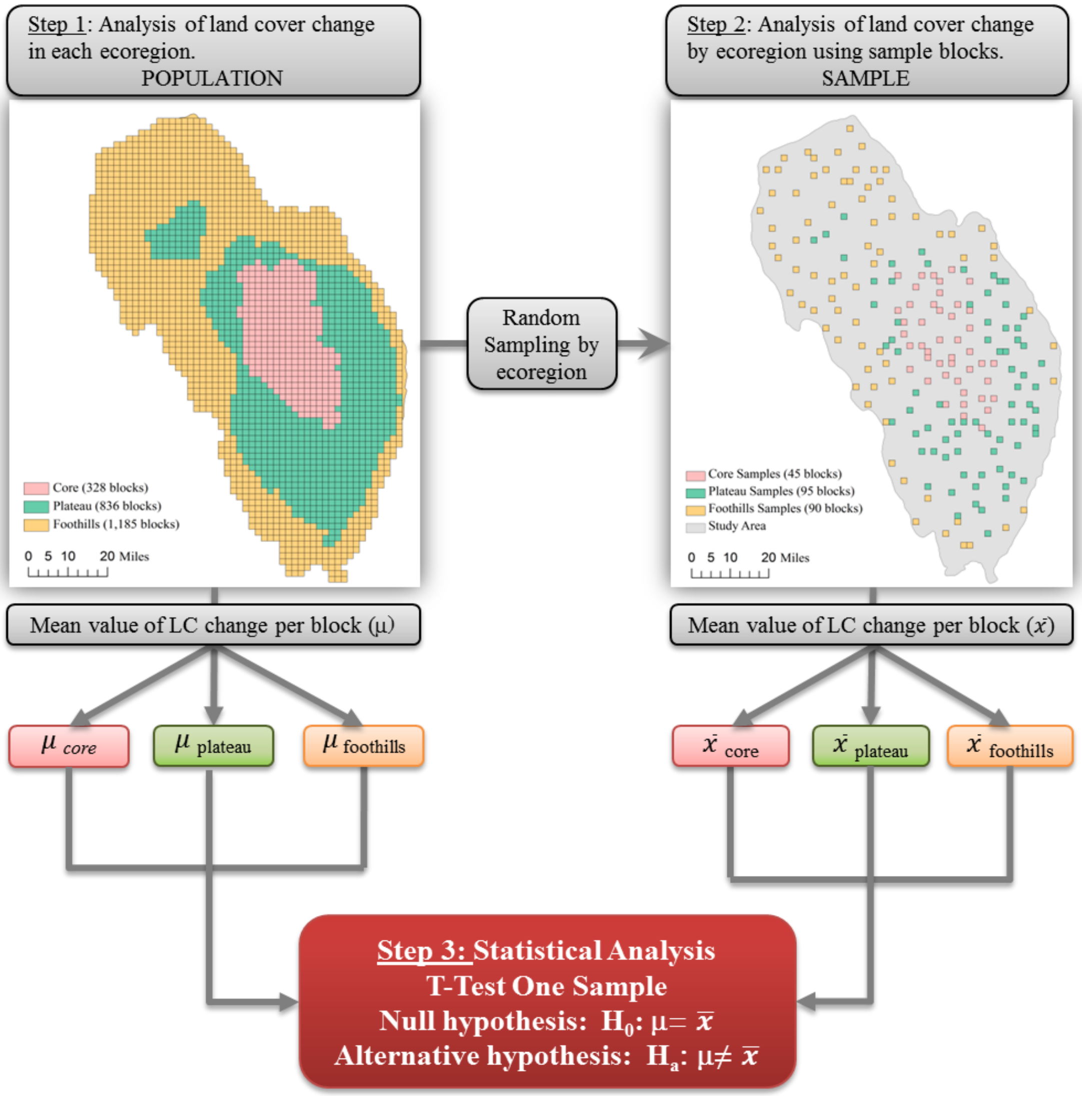

Figure 12. *Statistical approach used to determine the sample size required to analyze land cover change in each ecoregion of the Black Hills.*

time series mapping of land cover (Appendix C). The RLCM tool generates a digital dot grid for a given study area and the analyst identifies the discrete land cover class for each dot of the grid. This tool was used in this research because it allows accurate time series comparison, it facilitates land cover classification, and it is relatively rapid in comparison with traditional manual land cover mapping. I chose to map my samples using a resolution of 20 meters (*i.e.*, dots are 20 meters apart), which represents about 17,000 dots per sample. Because 195 study areas (samples) were too large to process with the

RLCM tool, I regrouped the samples by counties in order to have eight independent study areas to classify with the RLCM tool (Figure 13).

I began to map land cover using the 2010s imagery. I used some GIS layer data, such as roads, streams, land ownership, historic timber sales, and past fires layers, to help with the interpretation of each sample. For each block sample, I proceeded as follows:

1. Determine the main owners/managers of the land using ownership data from U.S. Geological Survey (2011).
2. Determine the most common land cover class and apply it to the entire sample (all the dots of the DG). Reclassify the dots deviating from that common class to map the other land cover classes until the sample was completely classified. The scale used to map land cover is 1:2,500 and the mapping unit was defined as four dots (*i.e.,* 0.04 hectares or 0.098 acres). Some exceptions were applied to “linear” land classes such as riparian areas and roads (*i.e.,* developed area) which were classified dot-by-dot (Figure 14).
3. When all the 2010 sample blocks were mapped, the 2010 land cover dot grid was copied over the 1950 imagery and the dots that changed land cover over time were re-classified.

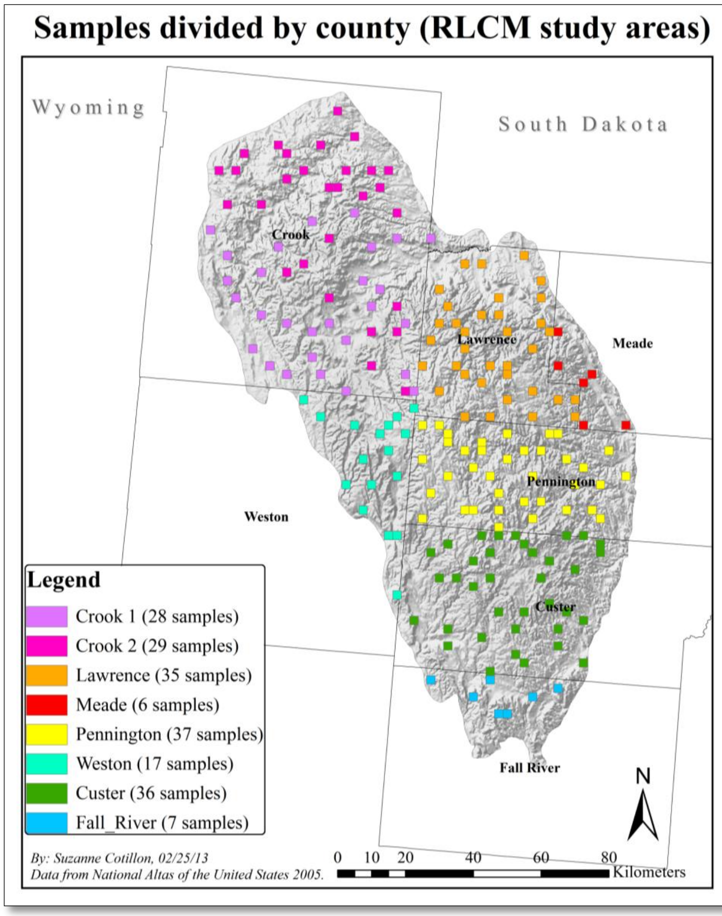

Figure 13. Study areas defined to process samples with the RLCM tool. Crook County samples had to be divided into two study areas because they were too

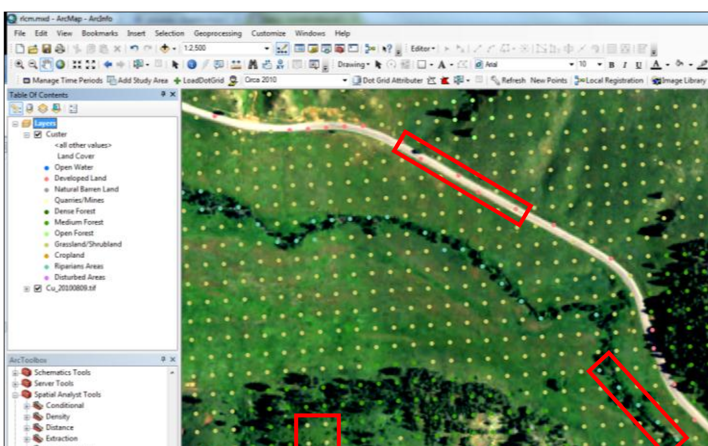

Figure 14. Example of mapping unit (red square) and linear land cover classes (red rectangles) such as riparian areas (blue dots) and roads (pink dots) considered while mapping land cover.

3.5.2. Quantification of Land Cover Changes Over Time

After all the sample blocks of each county were interpreted and processed for the 1950s and 2010s, I converted the land cover dot grids to rasters (20 m cell size) and then to polygons in order to estimate the area covered by each land cover class and determine land cover changes over time in the ecoregion. I calculated the net change in land cover, which represents the net loss or gain in each land cover class area between two time-periods. Moreover, I analyzed land conversions that took place when one land cover displaced another. These land conversions determine the proportion of one land cover that was changed to a new land cover in the next period and provide the overall gross[5] change that affected specific land cover. Because this study analyzes change between 1950 and 2010 without intermediary time-periods, some gross changes were missed. For instance, areas harvested in the 1960s could have burned in the 1980s, and thus only the result of fire was taken into consideration in the 1950-2010 land cover changes analysis.

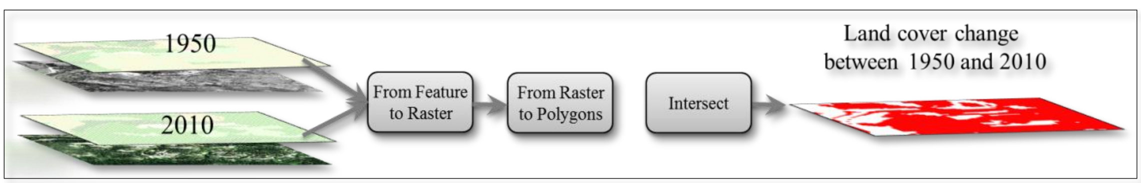

Figure 15. Processing steps to determine land cover change after classification using the RLCM tool.

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[5] Gross change provides clear evidence of the overall amount of land change experienced rather than the actual availability of specific land cover. For instance, in 1950, 50 percent of the area was dense forest and 50 percent was medium forest. In 2010, 5 percent of the area changed from dense to medium forest, 5 percent changed from dense forest to grassland, and 5 percent from medium forest became dense forest. The gross change of dense forest is 10 percent but its net change is -5 percent.

3.6. Assessment of Ecosystem Services Delivery

3.6.1. Typology of Ecosystem Services

The ES classification used in this study is drawn from the Millennium Ecosystem Assessment (2005). As in Potschin and Haines-Young (2011), the category 'supporting services' (*i.e.*, primary production, nutrient cycling, and soil formation) proposed by the Millennium Ecosystem Assessment (2005) was not considered because it is a synonym for ecological functions and processes that provide the other services, and by definition, these services are not directly used by people. Moreover, only the services that are relevant for the area were studied (Table 4).

Table 4. Definition and description of each ecosystem service delivered by the Black Hills landscape (de Groot, Wilson, and Boumans 2002; Froiland 1990; Hassan et al. 2005; Matlock and Morgan 2011).

ECOSYSTEM SERVICE	DESCRIPTION	IN THE BLACK HILLS
Provisioning services	**The products obtained from the ecosystems**	
Crops/forage	Production of food or forage by the ecosystems. Forage is the food available for wildlife and livestock on a given landscape. Available forage helps to reduce the cost to bring livestock up to market weight.	Most of the crops are alfalfa or other hay and winter wheat, whereas grassland/shrubland on public and private ranges provides most of the forage for livestock.
Minerals	Extraction of materials such as minerals, gravel, sand, and so forth.	Mineral extractions are visible in quarries for limestone, gravel, and sand, and in mines for ores (gold, silver, mica, and so forth).
Timber	Presence of tree species with potential use for commercial or individual logging.	Ponderosa pine, historically as well as presently, is the most valuable saw timber tree in the state.
Freshwater	Refers to the filtering, retention, and storage of water in streams, lakes, and aquifers. This retention and storage capacity depends on topography and subsurface characteristics of the involved ecosystem. This ecosystem service includes the consumptive use of water (by households, agriculture, and industry).	Presence of water reservoirs, such as Pactola Lake, help provide freshwater to metropolitan areas (mostly Rapid City).
Regulating services	**The benefits obtained from the regulation of ecosystems processes**	
Climate regulation	Ecosystems influence climate both locally and globally. At a local scale, changes in land cover can affect both temperature and precipitation. At the global scale, ecosystems play an important role in climate by either sequestering or emitting greenhouse gases.	The isolation of the Black Hills forest in the middle of the Great Plains creates a microclimate that reduces the extremes of temperature and conserve precipitation (Froiland 1990).

Water purification	Ecosystems can help to filter out and decompose organic wastes introduced into inland ecosystems. For example, wetlands and other aquatic ecosystems can treat relatively large amounts of organic wastes from human activities, acting as 'free' water purification plants.	Ponderosa pine forest, grassland/shrubland, and riparian areas are the main contributors to this service in the Black Hills.
Erosion control	Vegetative cover plays an important role in soil retention and the prevention of landslides. The erosion control (sometimes referred to as soil retention) ecosystem service depends on the structural aspects of ecosystems, especially vegetation cover and root systems. Plant roots stabilize soil, and foliage intercepts rainfall, which helps prevent compaction and erosion of bare soil, especially along riparian corridors and on steep slopes	When brown ponderosa pine needles fall they mulch the forest floor and reduce soil erosion by 60 percent compared to bare mineral soil (Ritchie, Maguire, and Youngblood 2005). Deep roots of vegetation also help reduce erosion on grassland/shrubland.
Water regulation	Water regulation deals with the influence of natural systems on the regulation of hydrological flows at the Earth's surface. This ecosystem service helps maintain a watershed's 'normal' conditions. Water regulation may include the maintenance of natural irrigation and drainage, buffering of extreme river and stream discharges, regulation of channel flow, recharging aquifers, and provision of a medium for transportation.	The forest canopy and root systems are very important factors in the hydrologic cycle to capture water from rainfalls, reduce run-off, and recharge groundwater. Reservoirs and wetlands attenuate possible floods by retaining water and storing it.
Cultural services	**The nonmaterial benefits people obtain from ecosystems though spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.**	
Spiritual and religious value	Many religions attach spiritual and religious values to ecosystems or their components. Spiritual ecosystem services are found through the sacred places we observe, and are reflected in the sacred places we build.	The entire Black Hills are considered to be sacred to members of the Great Sioux Nation. While specific places, such as Devil's Tower, Harney Peak, or the Black Elk Wilderness area are well known as public parks, they have religious and ceremonial significance for the Sioux. Other areas within the Hills are known through oral histories to be sacred: emergence points for human beings, places of healing waters, places for burial rites, gathering places of sacred medicines, and ceremonial grounds. All of these specific sites form a sacred unified landscape, the sum of which is sacred. Although individual places continue to be used for spiritual practices, the spiritual connection of the Sioux is to all of the Black Hills (White Face 2013).
Aesthetic value	Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, “scenic drives,” and the selection of housing locations. Aesthetic services are reflected in people’s preference for natural over built environment and preferences for wild over cultivated landscapes.	Many people enjoy the scenery of the forested and rural landscapes that make up much of the Black Hills region. This is evident in our preferences in living and recreating in these aesthetically pleasing environments . Indeed, people prefer landscape where nature dominates over human-modified features (Kaplan and Kaplan 1989, 40-49)
“Sense of place” and cultural heritage	Cultural heritage derives from the unique features of ecosystems that connect people to their history and ancestry. Many societies place high value on the maintenance of either historically important landscapes (“cultural landscapes”) or culturally significant species.	The Black Hills is rich in human history. The legacies of past explorations, Civilian Conservation Corps interventions in the 1930s, and of course Mount Rushmore are proofs of its cultural importance for people.

Recreation and ecotourism	Natural ecosystems have an important value as places where people can rest, relax, refresh themselves, and recreate. People often choose where to spend their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area.	The natural environment provides many opportunities for recreational activities, including hiking, boating, camping, hunting, fishing, swimming, and nature viewing.

3.6.2. Standard Production of Ecosystem Services

Land cover class is used as proxy variable to determine ecosystem services (ES) production. Each type of land cover produces a different set of ecosystem goods and services at different levels. To assess the different land cover types' capacities to provide ecosystem services, a matrix was created. On the y-axis of the matrix, the land cover types are placed. On the x-axis, the ecosystem services selected for the study are placed (*cf.* Appendix D). At the intersection, an index (or score) of production P_n^i (0=null, 1=low, 2=medium, 3=high) is assigned to each coupled land cover *i* /ecosystem service *n* to estimate the contribution of each land cover to ecosystem service provision. The index refers to the ES provided by a particular area and actually used within a given time period. Furthermore, the score is not related to the value of a service but only to its potential level of production by a land cover. The production of each service is based upon the performance of ecological structures, processes, and functions (Muller, Groot, and Willemen 2010, 2). For example, forests are more able to sequester carbon and so regulate climate than grassland because of the presence of trees, while grasslands have a better capability to prevent soil erosion than cropland because of their deeper and more continuous root system. It is necessary, however, to emphasize that these values can vary depending on the species present in each ecosystem.

These production levels (P_n^i) allow the calculation of the potential production of ES of each land cover (PP_i) and the potential supply of each ecosystem service by the multiple land covers landscape (PS_n) (Figure 16). The potential production (PPi), which is the sum of the level of production (P_n^i) for each ecosystem service *n* produced by land cover class *i*, highlights the capacity of one land cover to produce different ES (Formula 1, Figure 16). It reflects the possible ES production assuming the full functionality of the ecosystems. Similarly, the potential supply (PS_n) of the ecosystem service *n* by the landscape is the sum of the production levels for all land cover classes producing the ecosystem service *n* (P_n^i) and highlights the capacity of the whole landscape to deliver this service (Formula 2, Figure 16). These two notions allow the comparison of land cover productivity on one hand, and ES delivery on the other.

Formula 1: Potential production of ecosystem services by land cover *i*,

$$PPi = \sum_{n} P_{n}^{i}$$

Formula 2: Potential supply of one ecosystem service *n* by a multiple land covers landscape,

$$PS_n = \sum_{i} P_{n}^{i}$$

With: **i**= land cover {Open forest, grassland… open water}
n= ecosystem service {Crops/forage, timber …, recreational}
$\mathbf{P_n^i}$= level of production of the ecosystem service n by the land cover *i* {0, 1, 2, 3}
$\mathbf{PP_i}$= potential production of ES by the land cover *i*
$\mathbf{PS_n}$= potential supply of the ecosystem service *n* by the landscape

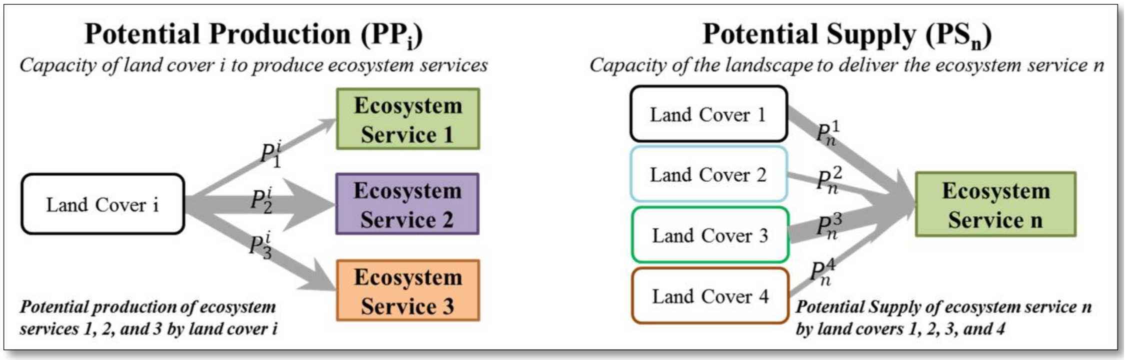

Figure 16. Concepts of potential production of one land cover, and potential supply of one ecosystem service by a landscape.

3.6.3. Production of Ecosystem Services Normalized by Land Area

To compare ES production by land cover, it is necessary to consider the area of each land cover class. Indeed, although one land cover class may produce most ES, its potential production will not be significant if its proportion in the study area is small (*i.e.*, wetland). To consider this factor, the potential production of each land cover and the potential supply of each ecosystem service are normalized by land cover area using Formula 3 and Formula 4. The potential production normalized by land cover area (NPP_i) highlights the contribution of each land cover class to the total production of ES in the study area. The potential supply normalized by land cover area (NPS_n) emphasizes the delivery of the ecosystem service *n* by the whole landscape.

<u>Formula 3:</u> Potential production of land cover *i* normalized by area,

$$NPP_i = PP_i * A_i$$

$$NPP_i(\%) = \left(NPP_i \Big/ \sum_i NPP_i \right) * 100$$

Formula 4: Potential supply of one ecosystem service *n* by a multiple land covers *i* landscape normalized by land cover area,

$$NPS_n^i = \sum_i (P_n^i * A_i)$$

$$NPS_n^i(\%) = \left(NPS_n \Big/ \sum_n NPS_n \right) * 100$$

With **i**= land cover {Open forest, grassland… open water}
n= ecosystem service {Crops/forage, timber…, recreational}
PP_i= potential production of ES by the land cover *i*
A_i= Percentage of the land cover *i* area in the ecoregion
P_n^i = level of production of the ecosystem service n by the land cover *i* {0, 1, 2, 3}

3.6.4. Land Cover Changes and Consequences on Ecosystem Services Delivery

Land cover conversion describes the change from one land cover to another over time. It results in a net decrease or increase in the area of some land cover classes (Figure 17). Because each land cover class produces various ES at different levels, the conversion of one land cover to another directly influences the production of ES and, as a result, each ecosystem service supply is affected. For instance, if land cover *i* increases its surface over time, its contribution to the total ES production will be more important. At the landscape scale, the switch in land cover areas will change the total delivery of each service over time (Formula 5).

Formula 5: Change in normalized potential supply of ecosystem services by the landscape between time 1 (land covers *i*) and time 2 (land covers *k*),

$$\text{Relative change: } \Delta\, NPS_n^{i \to k}(\%) = (NPS_n^{\mathrm{k}} - NPS_n^i)/NPS_n^i * 100$$

$$\text{Net change: } \Delta\, NPS_n^{i\to k}(\%) = NPS_n^{\mathrm{k}}(\%) - NPS_n^{i}(\%)$$

With: **i**= land cover in time 1 {Open forest, grassland… open water}
k= land cover in time 2 {Open forest, grassland… open water}
n= ecosystem service {Crops/Forage, timber…, recreational}
$\mathbf{NPS_n^i}$= the normalized potential supply of the ecosystem service *n* by the multiple land covers *i* landscape.

The potential supply of ES by the land covers k landscape (time 2) is calculated by Formula 4 as NPS_n^{i} but using the percentage of the land cover k area in the ecoregion resulting from land cover changes (A_k). At the end, Formula 5 explains the relative and net changes of potential of ES supply by the landscape ($\Delta\, NPS_n$) resulting from land cover change between time 1 and time 2.

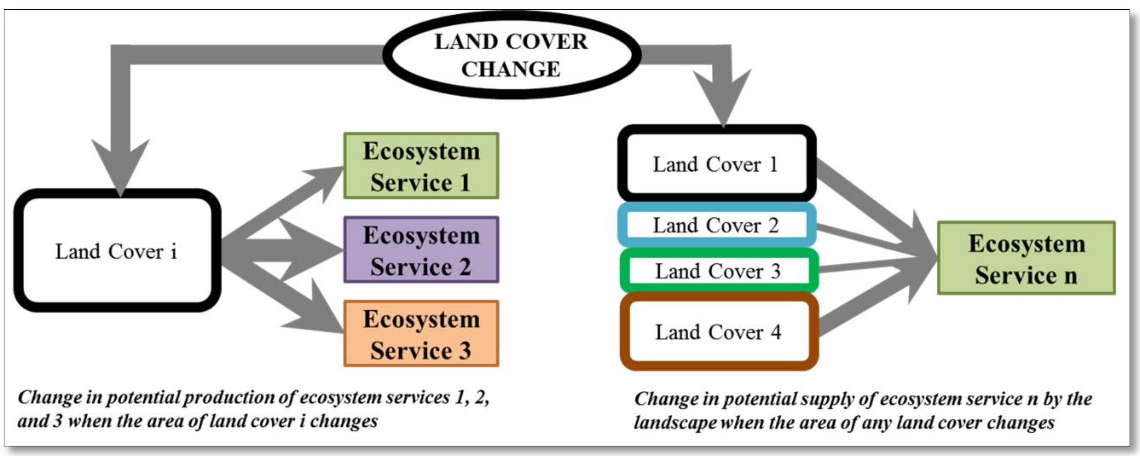

Figure 17. Impacts of land cover change on potential production and potential supply of ES. The sizes of boxes is relative to the change in land cover area, and the size of arrows indicates the associated change in level of ES production.

3.6.5. Impact of Land Management on Ecosystem Services Delivery

Land use and management influence the system properties, processes, and components that are the basis of ecosystem services provision (de Groot et al. 2010). Therefore, to address the third objective of my thesis research (*i.e.,* analyze the results of past and current land management on ecosystem services delivery), I looked at land cover changes and their consequences on ecosystem delivery in different parts of the Black Hills. I used three case studies to demonstrate the influence of land management on ecosystem services delivery over time: the Black Hills National Forest (BHNF), Custer State Park (CSP), and Wind Cave National Park (WCNP).

To capture the variability of land cover in WCNP and CSP, which covered smaller areas than the BHNF, one additional sample was selected both in WCNP and CSP. As a result, the sampled areas in the case studies represent respectively 11.2 percent, 7.9 percent, and 12.4 percent of the BHNF, CSP, and WCNP areas (Figure 18).

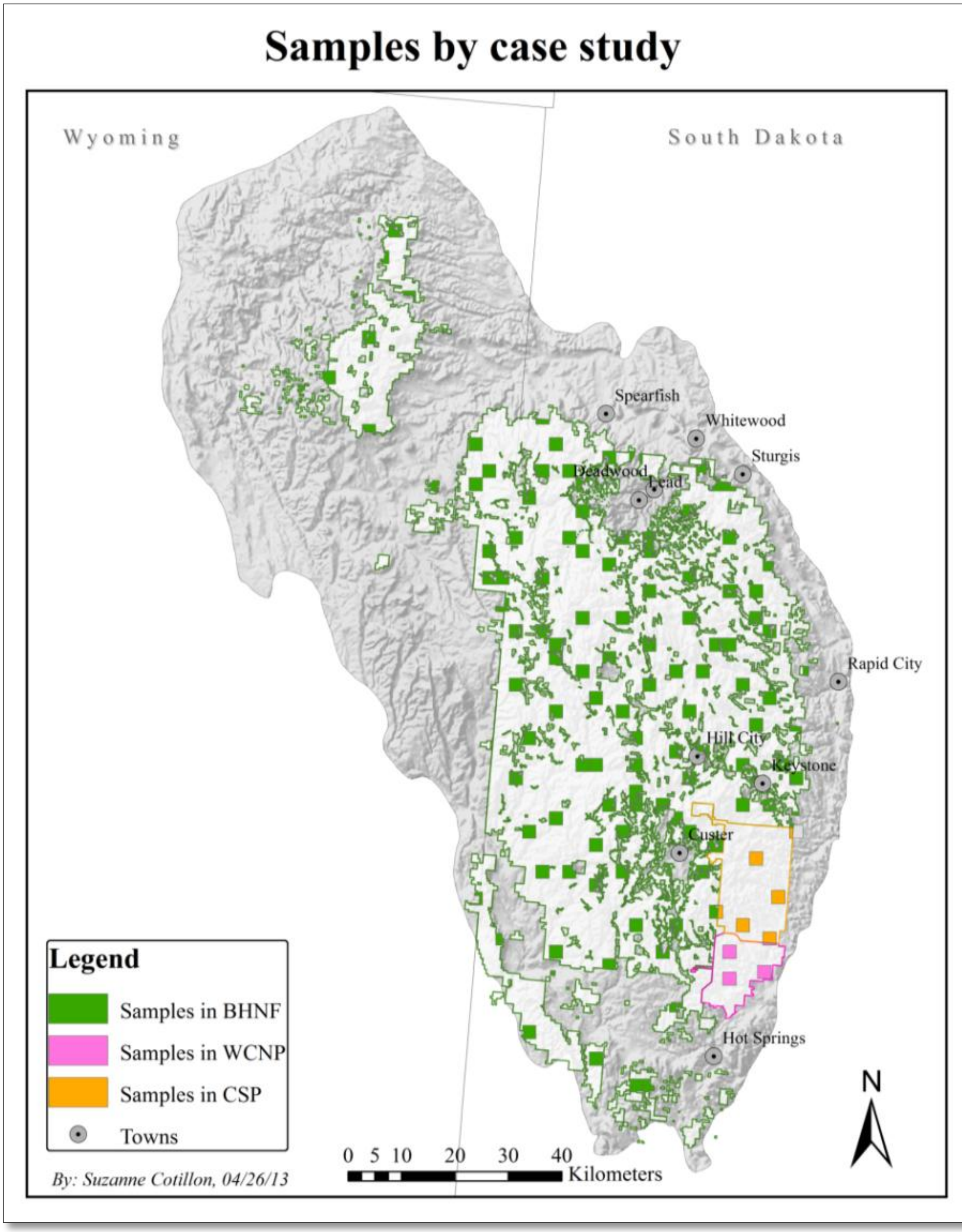

Figure 18. Location of the samples in the three case study areas: the Black Hills National Forest, Custer State Park, and Wind Cave National Park.

CHAPTER 4. RESULTS

4.1. Land Cover Change Analysis for the Ecoregion

The ecoregion landscape is primarily a mosaic of forested and grassland/ shrubland areas. Both in 1950 and 2010, dense forest and grassland/shrubland were the main land cover classes and contributed more than 65 percent of the total land cover (Figure 19 and Figure 20). Together, medium and open forests formed 21.6 percent of the total ecoregion land cover in 1950 and 28.8 percent in 2010. The remaining land was covered by cropland (3.6 percent in 1950 and 3.7 percent in 2010), natural barren land (0.4 percent), developed land, and riparian areas.

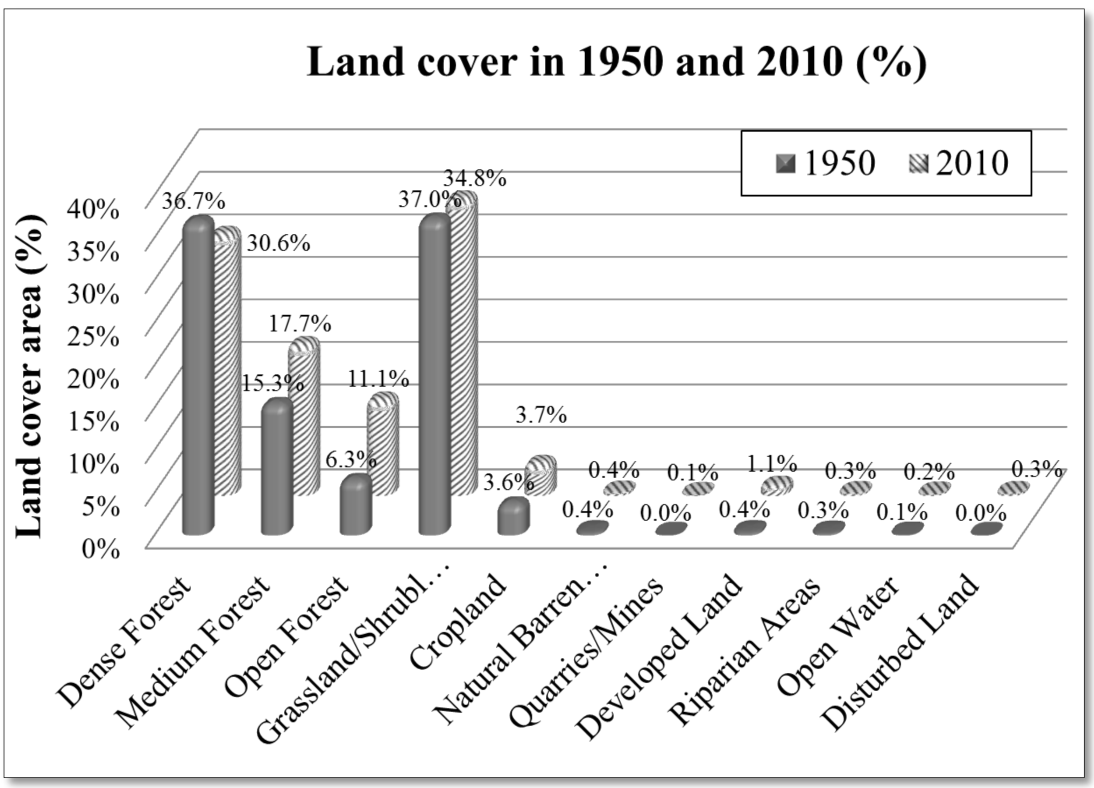

Figure 19. Proportions of each land cover class in the Black Hills ecoregion in 1950 and 2010. Disturbed areas could not be classified in 1950.

4.1.1. Land cover characteristics

In order to better understand the characteristics of each land cover unit within the Black Hills landscape, the land cover maps of sampled areas in 1950 and 2010 were intersected with elevation and slope GIS layers derived from the Digital Elevation Model of the region (30 meters resolution). The results show a similar pattern for both years (*Figure 21*). On average, cropland and riparian areas are located at lower elevations and moderate slopes (< 6 percent). Developed land, grassland/shrubland, and natural barren land are all located between 1,400 and 1,450 meters of elevation, but natural barren land occurred on steep slopes (around 14 percent). At higher elevations, the main land cover classes are the forests. Disturbed areas, which are areas infested by the mountain pine beetle, are located at the highest altitudes (1,800-1,850 meters) on steeper slopes (18 percent). Between 2010 and 1950, however, the quarries/mines class moved to lower elevation and slopes, and the distribution of forested land changed as well. In 2010, open forest could be found at a higher elevation whereas dense forest was more likely to be at lower parts of the ecoregion. Disturbed areas, which could not be classified on 1950s photographs, were located at the highest altitude and steeper slopes in 2010. That can be explained by the fact that mountain pine beetle infestations are more likely found in dense forest and thus at higher elevation, but also where access is more difficult and tree treatment more challenging.

Similarly, the size of the land cover classes polygons followed the same pattern in 1950 and 2010 (Figure 22). Developed land, riparian areas, and open water consisted of parcels smaller than 0.5 hectare, and natural barren land polygons are mostly smaller than one hectare. Forests, grassland/shrubland, and quarries/mines are more heterogeneous

Land cover in sampled areas of the Black Hills ecoregion

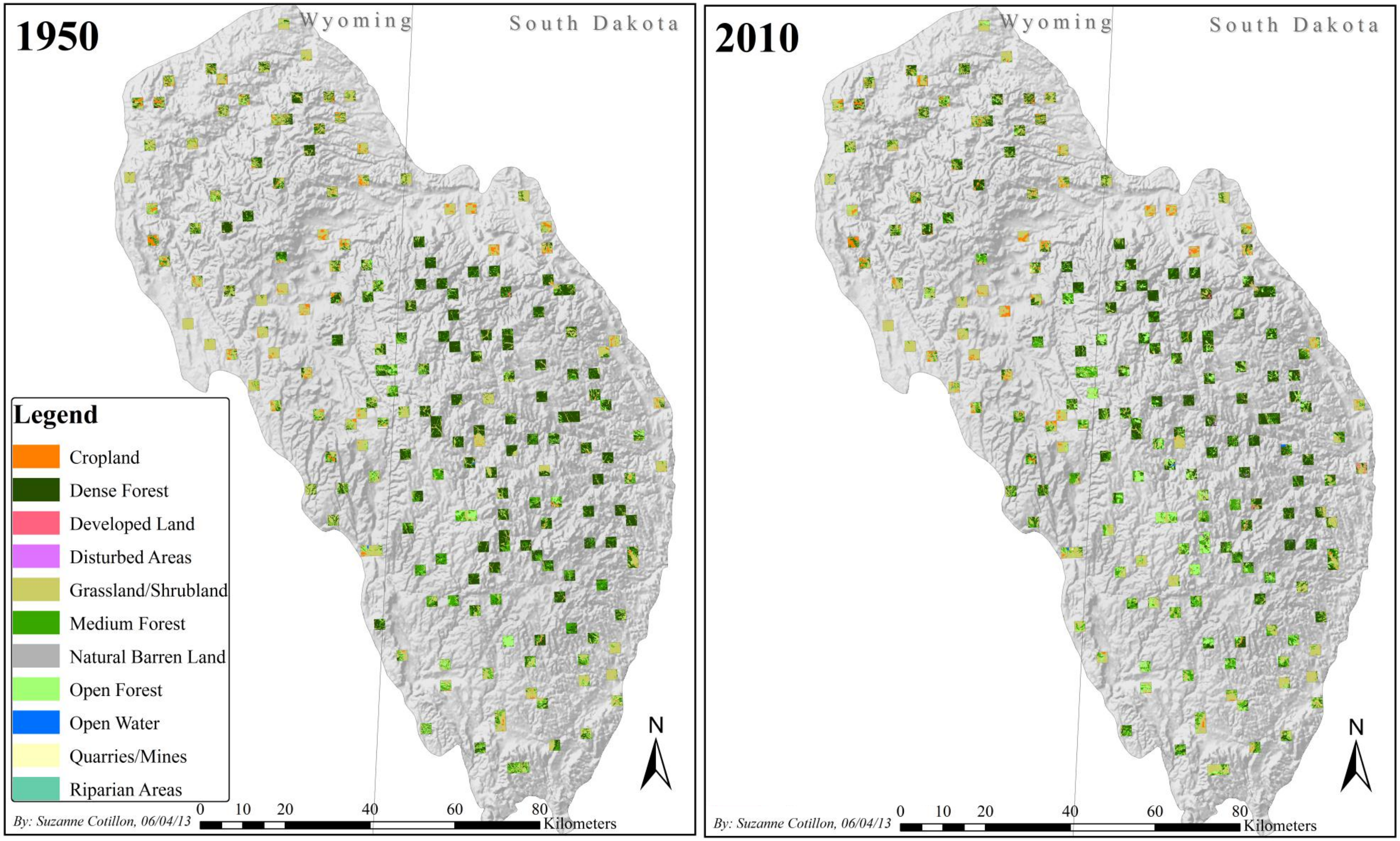

Figure 20. The Black Hills ecoregion land cover maps in 1950 and 2010. Disturbed areas could not be classified in 1950.

in term of parcel sizes, which are mostly smaller than 5 hectares. Cropland is the class composed of the largest parcels (between 5 and 30 hectares). Between 1950 and 2010, the main changes were an overall increase of parcel size for the forests classes, quarries/mines, and cropland.

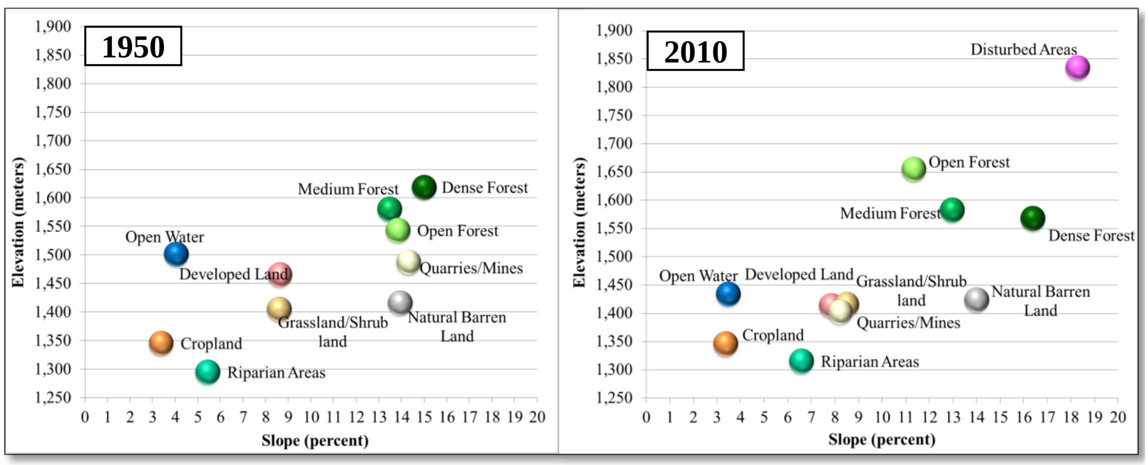

Figure 21. Location of the land cover classes by elevation and slope in the Black Hills ecoregion. The values are means of all polygons for each land cover class. Disturbed areas could not be classified in 1950 because the historical photos were in black and white.

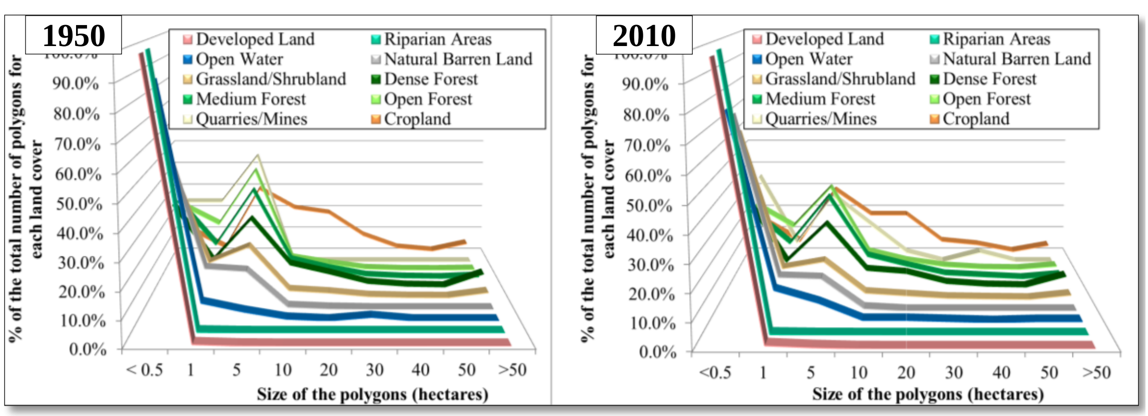

Figure 22. Repartition of land cover by polygon sizes in 1950 and 2010. Disturbed areas are not considered in this figure.

4.1.1. Land cover changes in the ecoregion

Land cover changes occurred everywhere in the Black Hills ecoregion between 1950 and 2010 (Figure 25). Overall, 41.3 percent of the sampled area changed during the study period. Changes mostly occurred on small parcels (less than 5 hectares) and only 5 percent of the change polygons were larger than 5 hectares. The results of the change analysis indicate a net increase in forested covers over grassland/shrubland cover (Figure 2523, 24, and 25). Furthermore, there was a change in forest structure between 1950 and 2010. Dense forest was converted to medium forest (6.7 percent of the total sampled area) and open forest (4.7 percent), which resulted in a net increase in both land cover areas. There were also some areas of grassland/shrubland that were encroached upon by pine and other forest growth, which contributed to the net reduction in grassland/shrubland cover area. Smaller changes included net increases in developed land and cropland (respectively +0.7 and +0.1 percent) mostly from grassland/shrubland conversion (Figure 2523, 24, and 25).

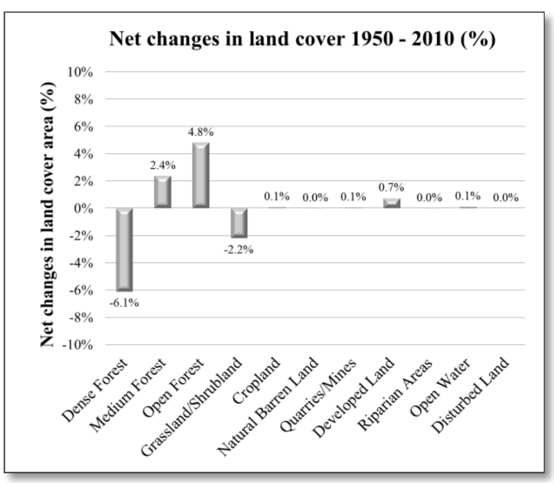

Figure 23. Net land cover change by class in the Black Hills ecoregion. For example, the area covered by dense forest decreased in 6.1 percent (from 36.7 percent to 30.6 percent) in the past 60 years.

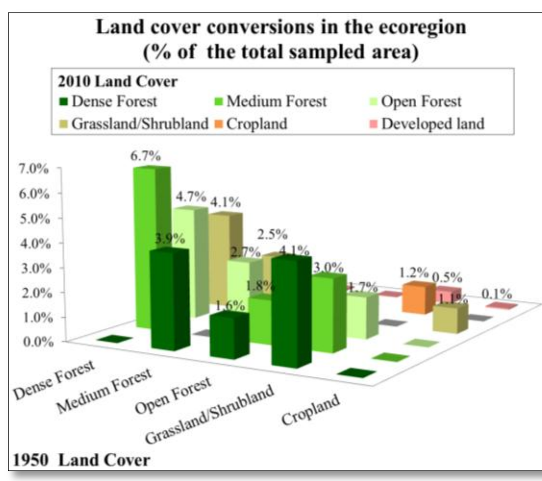

Figure 24. Main land cover conversions in the Black Hills ecoregion. For example, 6.7 percent of the total sampled area switched from dense to medium forest, and 4.7 percent switched from dense to open forest.

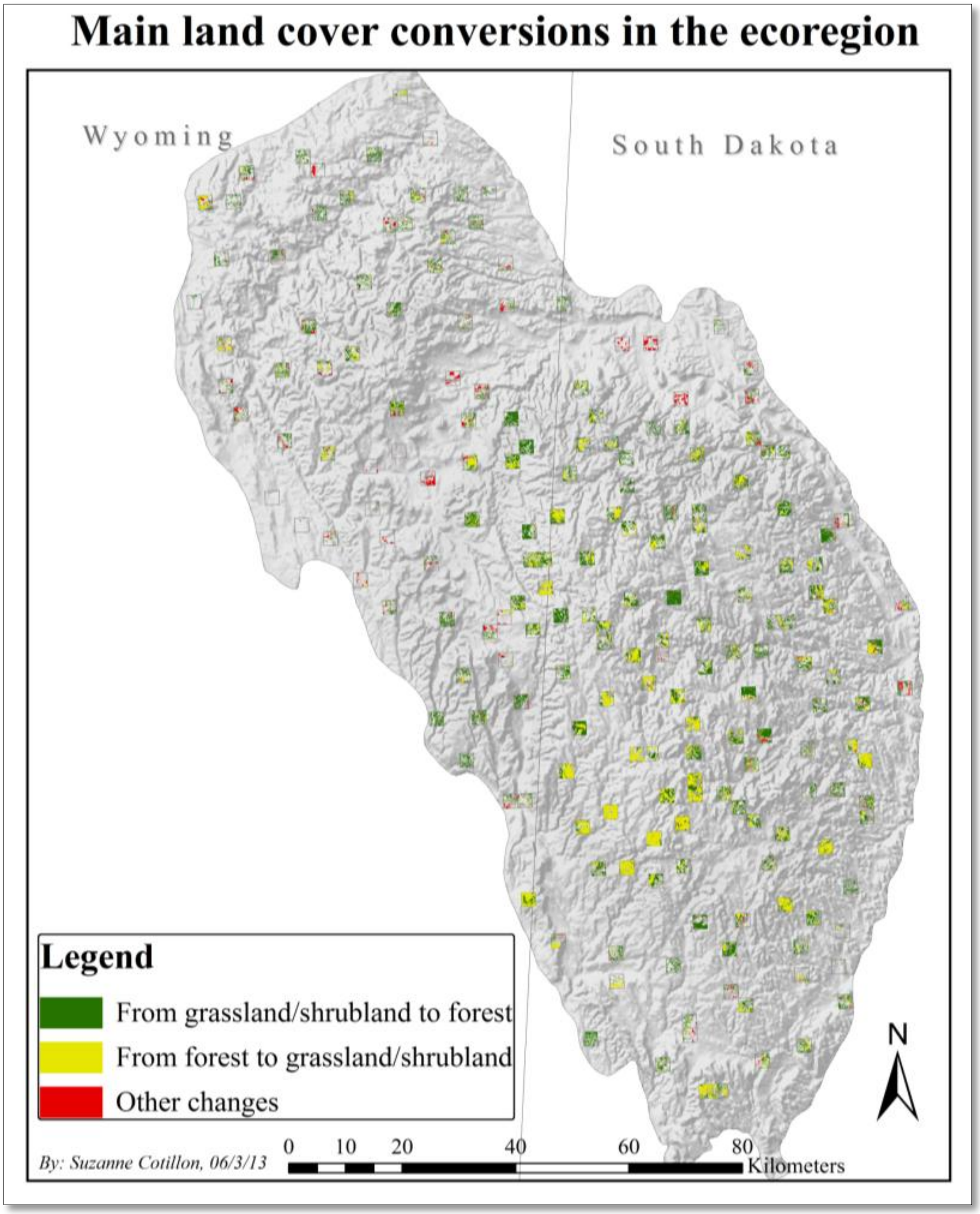

Figure 25. Map of the major land cover conversions (loss and gain of forest) within the sampled areas. The forest category comprises dense, medium, and open forests.

4.1.2. Spatial distribution of changes

As described previously, the Black Hills ecoregion is composed of three distinct sub-ecoregions. The dominant vegetation of the central part of the Black Hills, the granitic core and the limestone plateau, is dense forest (about 50 percent in the core and 40 percent in the plateau) whereas the surrounding foothills are mostly covered by grassland/shrubland (about 55 percent). Consequently, these sub-ecoregions had different patterns of land cover changes (Figure 26 and Figure 27).

Land cover changes occurred mainly in the core and the plateau sub-ecoregions (respectively 48.0 and 47.4 percent of the sampled area changed) whereas only 27.4 percent of the foothills sampled area changed. Both in the core and the plateau, dense forest was converted to medium forest (respectively 9.9 and 9.1 percent of the total sampled area), open forest (respectively 9.2 and 5.7 percent), and grassland/shrubland (respectively 3.8 and 6.1 percent). These conversions lead to a net decrease of dense forest and an increase in both medium and open forest areas in these two sub-ecoregions.

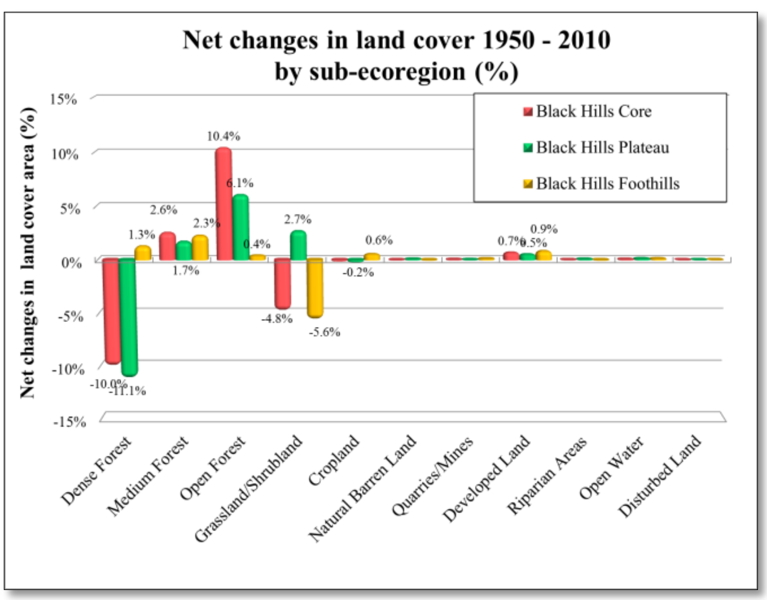

Figure 26. Net land cover changes in each sub-ecoregion.

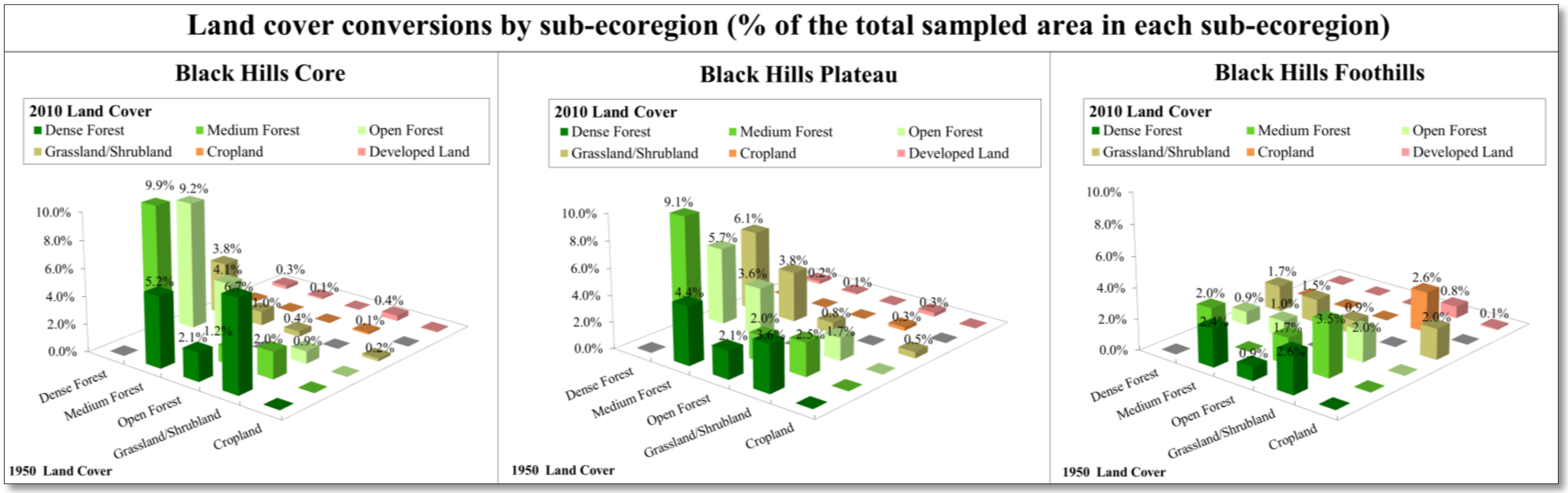

Figure 27. Land cover conversions in each sub-ecoregion between 1950 and 2010. To maximize the readability of the graph, only the major land conversions are represented.

In the core, however, there was a net loss of grassland/shrubland because of the regrowth of dense forest after 1950, whereas in the plateau land conversions resulted in a gain of grassland/shrubland area. In the foothills, in contrast, there was a net gain of forested land over grassland/shrubland area, which decreased 5.6 percent between 1950 and 2010, and a net increase in cropland area (+0.6 percent). Finally, developed land increased within each of the three sub-ecoregions. These results confirmed that change is heterogeneous within the Black Hills ecoregion. Each sub-ecoregion has its own land uses and land covers, and was subject to different drivers of changes.

4.2. Ecosystem Services in the Ecoregion

4.2.1. State of Ecosystem Services in the 1950s

Based on a review of the literature and expert evaluations, the matrix of land cover production of ecosystem services (P_n^i) was created for the whole ecoregion. To build this overall matrix, it was necessary to make compromises among different management views. Indeed, as described before (*cf.* 3.2.3.), the management of the ecoregion is shared among several agencies, and their management policies influence the capacity of land cover types to provide services. Since the U.S. Forest Service is the primary manager of the area, most of the indices for the ecoregion are based upon the matrix elaborated for the Black Hills National Forest (*cf.* Appendix D). Consequently, all forested areas are considered as a source of timber production even if logging does not occur everywhere.

In the Black Hills ecoregion, the different forest land cover types, grassland/shrubland, and riparian areas, show a high capacity to provide a broad range of ecosystem services, especially regulating and cultural services. Moreover, many near-nature land cover types reveal rather high capacities to support ecosystem services production, whereas human-modified landscape, such as developed land, cropland, or quarries/mines, have lower potential services production levels (Table 5 and Figure 28). In the ecoregion, ecosystem services are mostly provided by dense forest and grassland/shrubland, which were the dominant land cover classes in 1950. Consequently, these land cover classes were the main contributors to ES delivery. The most delivered services were water purification, erosion control, spiritual and religious values, aesthetic value, climate regulation, and recreation/ecotourism. Provisioning services, such as crops/forage and timber production were also well provided by the land cover units of the ecoregion (Figure 29).

Table 5. Land cover classes and ecosystem services levels of production (P_n^i) in the Black Hills ecoregion. For definition of land cover types and ecosystem services see Table 4 and Appendix B. The assessment scale is as follows: 0= no production of the service by the land cover type, 1= low level of production, 2= medium level of production, and 3= high level of production. The justification for each index is given in Appendix D.

	PROVISIONING SERVICES				REGULATION SERVICES				CULTURAL SERVICES			
	Crops /Forage	Minerals	Timber	Fresh-water	Climate Regulation	Water purification	Erosion Control	Water Regulation	Spiritual/ Religious	Aesthetic	"Sense of a place"/ cultural heritage	Recreational
Dense Forest	0	0	3	0	3	3	3	2	3	2	2	3
Medium Forest	1	0	2	0	3	3	3	2	3	3	2	3
Open Forest	2	0	0	0	2	3	3	2	3	3	3	3
Grassland/ Shrubland	3	0	0	0	2	3	3	1	3	3	3	3
Cropland	3	0	0	0	1	0	1	1	0	0	0	0
Natural Barren Land	0	0	0	0	0	0	0	0	3	3	2	3
Quarries/Mines	0	3	0	0	0	0	0	0	0	0	0	0
Developed Land	0	0	0	0	0	0	0	0	0	0	3	3
Riparian Areas	0	0	0	3	3	3	3	3	0	3	0	1
Open Water	0	0	0	3	0	0	0	3	0	3	1	3
Disturbed Land	2	0	0	0	0	0	0	0	0	0	0	0

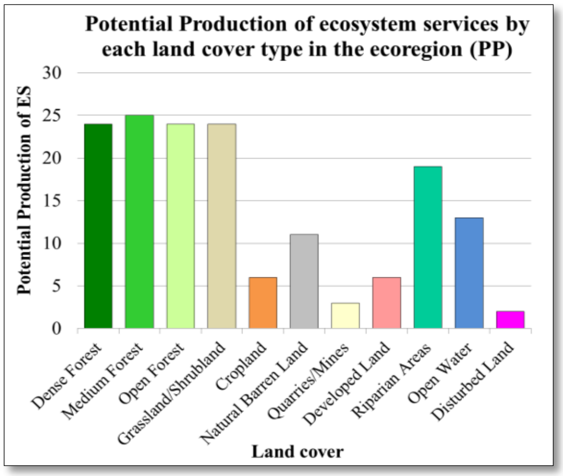

Figure 28. Potential production of ecosystem services by each land cover in the Black Hills ecoregion (calculated from Formula 1).

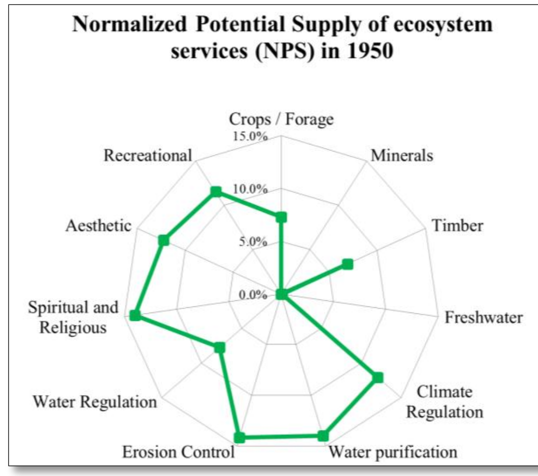

Figure 29. Potential supply of ecosystem services normalized by land cover area in the Black Hills ecoregion in 1950 (calculated from Formula 4).

4.2.2. Impacts of Land Cover Changes on Ecosystem Services Delivery

Land conversions in the ecoregion were numerous between 1950 and 2010 and resulted in loss of dense forest and grassland/shrubland areas, and in expansion of medium and open forests (Figure 23 and Figure 24). Since open and medium forests produced multiple services at high levels, the net increase in their areas enhanced the level of forage production, and aesthetic value in the ecoregion (Figure 30). In contrast, medium and open forests produced a lower level of timber, climate regulation (through carbon storage), water purification, erosion control, and spiritual and religious value than dense forest. Thus, the change in forest structure that occurred in the ecoregion led to a net decrease in the delivery of these services. On the other hand, some minor land conversions had a direct impact on the delivery of some services. For example, the construction of new quarries/mines (+0.1 percent of the total sampled area) slightly increased the level of production of minerals. Similarly, the gain of riparian and open water areas (respectively +0.01 and +0.12 percent of the total sampled area) raised the level of freshwater production (+0.02 percent), but also contributed to higher aesthetic, sense of place, and recreation/ecotourism values.

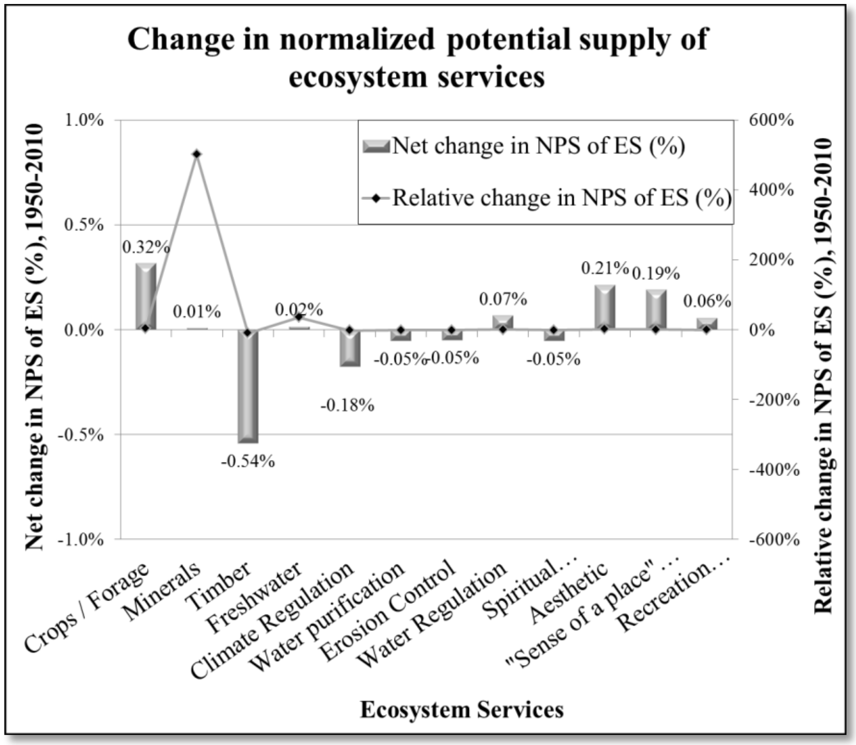

Figure 30. Changes in normalized potential supply of ES (NPS) in the ecoregion between 1950 and 2010 (calculated from Formula 5). For example, the normalized potential supply of crops/forage increased 0.32 percent (from 6.40 to 6.72 percent of the total ES supply by the ecoregion land cover).

4.3. Application of the Method on Three Case Studies

4.3.1. The Black Hills National Forest

4.3.1.1. Description and Historical Background

The Black Hills National Forest covers over 505,860 hectares (1.25 million acres) of the Black Hills ecoregion, which makes the U.S. Forest Service the most important manager of the ecoregion in terms of area. Following its establishment in 1905, the Black Hills National Forest (BHNF) was chosen as a place to demonstrate scientific forestry methods because local industry was highly dependent on forest productivity.

The BHNF could easily accommodate all of Gifford Pinchot[6]'s desired multiple-uses and the numerous management plans have been the result of many years of trying to balance the multiple uses of grazing, timbering, mining, wildlife, and outdoor recreation (Geores 1996). In the past century, tremendous shifts among land uses occurred in the BHNF. Following the growth of mining as the primary use of the Black Hills in the early 1900s, timbering, grazing, and recreation began to develop. Each land management activity was designed to optimize the productivity and intensity of the various land uses, according to the concept of multiple uses defined first by Pinchot and later codified in the Multiple Use Sustained Yield Act (MUSY) of 1960. The Act imposed a transition phase and the notion of balancing competing uses in relation to their relative economic values, which led to a hierarchy among the industries. Economic activities, such as mining, logging, and ranching, are still priorities in the Black Hills National Forest Plan.

In the 20th century, the public increasingly looked to national forests as places to relax. In part as a response to the environmental devastation caused by the Dust Bowl droughts and Great Depression, President Franklin Roosevelt created the Civilian Conservation Corps (CCC) in 1933. That year, corpsmen arrived in the Black Hills where they built campgrounds, dams, picnic areas, lakes, and other recreational developments, which greatly improved outdoor recreation opportunities (Sanders 2004; USDA 1996a). Pactola Lake, Sheridan Lake, and Sylvan Lake quickly became major recreation areas for boaters, fishermen, and campers in the Black Hills. The reputation of the Black Hills as a recreational center grew as a large result of the CCC workers' activities between 1933 and 1942.

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[6] Gifford Pinchot served as the first Chief of the United States Forest Service. Pinchot is known for reforming the management and development of forests in the United States and for advocating the conservation of the nation's reserves by planned use and renewal (Geores 1996).

In the BHNF, several areas are managed for reservation purposes but at different levels. The Black Elk Wilderness Area, included in the Norbeck Wildlife Preserve, was officially designated as wilderness under the Wilderness Act of 1964 (USDA 1996a). In the Black Elk Wilderness Area, located in the central Black Hills near Hill City, covers 13,426 acres. The U.S. Forest Service allows no motorized or mechanized vehicles, including bicycles, although camping and fishing are allowed with proper permits, as well as hunting in season. No roads or buildings are constructed, and there is no logging or mining, in compliance with the 1964 Wilderness Act. The wilderness issue is important because wilderness land is managed by not being managed. The trees are not thinned, infestations of insects are not treated, and wildfires are only minimally contained to prevent them from spreading out of the wilderness area (Geores 1996). The sampled area in the Black Elk Wilderness Area represents only 1.5 percent of the BHNF area and thus was not considered in this study.

4.3.1.1. Land cover changes

Most of the BHNF is located within the Limestone Plateau, which surrounds the Core of the Black Hills. Thus, like in the core and the plateau, the main vegetation of the BHNF is dense forest associated with some patches of medium forest, open forest, and grassland/shrubland (Figure 31). Most of the dense forest is located in the center of the National Forest whereas grassland/shrubland and open and medium forests are dominant in the southern foothills. In 1950, 57.4 percent of the National Forest was covered by dense forest, 19.8 percent by medium forest, 14.4 percent by grassland, and 7.6 percent by open forest. By 2010, 52.8 percent of the sampled area had changed (Figure 31). The main net land cover changes in the BHNF were the loss of dense forest (-12.7 percent of

Land cover in sampled area of the Black Hills National Forest

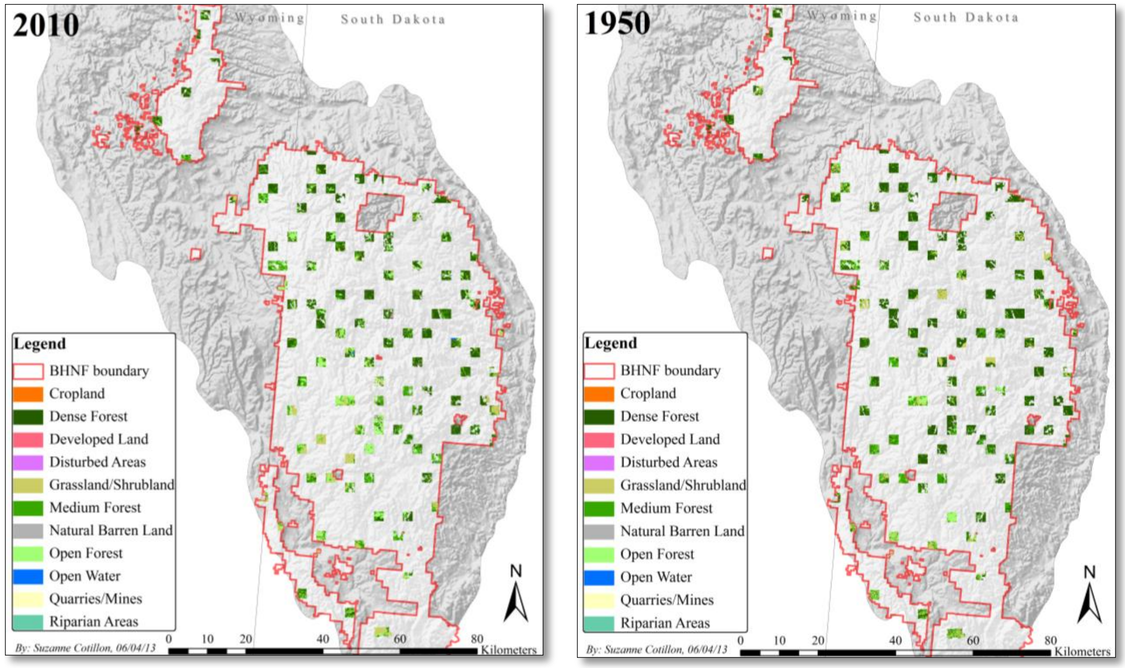


Figure 31. Black Hills National Forest land cover maps in 1950 and 2010. The boundary of the BHNF is simplified on these maps.

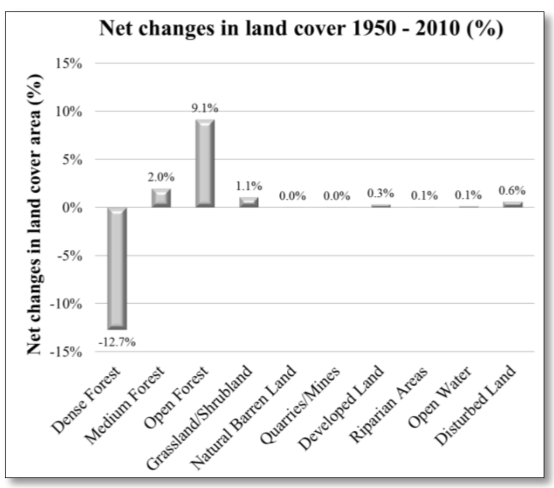


Figure 32. Net changes in land cover area between 1950 and 2010 in the BHNF. For example, the area covered by dense forest decreased 12.7 percent (from 57.4 percent to 44.7 percent) for the past 60 years.

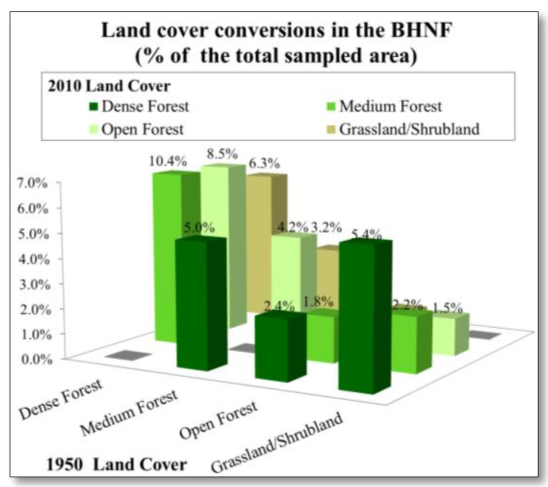


Figure 33. Main land cover conversions in the BHNF between 1950 and 2010. For instance, 8.5 percent of the sampled area in the BHNF switched from dense to open forest, and 10.4 switched from dense to medium forest.

the sampled area) and the gain of open forest (+9.1 percent). These changes can be explained by the conversion of dense forest to medium forest, open forest, and grassland/shrubland, which did not balance with forest regrowth (Figure 32 and Figure 33). Furthermore, some forestland was converted to pasture and range (grassland/shrubland) for livestock, some has been cleared for urban, residential, and recreation development (developed land), and some has been cleared for reservoir sites (open water) (Figure 32 and Figure 33).

4.3.1.2. Consequences of Land Cover Changes on Ecosystem Services Delivery

The National Forest's management seeks to balance multiple-uses while providing "the greatest good for the greatest number over the longest period of time" (Geores 1996). Land management of these areas focuses on timber harvesting, livestock grazing, water, wildlife, and recreation. In the BHNF, forested land, grassland/shrubland, and riparian areas provide most of the services (Table 6). Similarly, as in the whole ecoregion, the most delivered services in the BHNF were recreation/ecotourism, spiritual, and religious values, water purification, and climate regulation in 1950. Furthermore, timber production is the most important provisioning service in the BHNF (Figure 34).

Because of the loss of dense forest, the BHNF landscape delivered lower levels of timber (-1.46 percent) and climate regulation (-0.48 percent) in 2010, meanwhile the conversion of dense forest to other land covers, especially open forest, increased the level of supply in forage, aesthetic, and heritage values in the landscape (Figure 35).

Table 6. Land cover classes and ecosystem services levels of production (P_n^i) in the Black Hills National Forest. For definition of land cover types and ecosystem services see Table 4 and Appendix B. The assessment scale is as follows: 0= no production of the service by the land cover type, 1= low level of production, 2= medium level of production, and 3= high level of production. The justification for each index is given in Appendix D.

	PROVISIONING SERVICES				REGULATION SERVICES				CULTURAL SERVICES			
	Crops /Forage	Minerals	Timber	Fresh-water	Climate Regulation	Water purification	Erosion Control	Water Regulation	Spiritual/ Religious	Aesthetic	"Sense of a place"/ cultural heritage	Recreation /Ecotourism
Dense Forest	0	0	3	0	3	3	2	2	3	2	2	3
Medium Forest	1	0	2	0	3	3	2	2	3	3	2	3
Open Forest	2	0	0	0	2	3	2	2	3	3	3	3
Grassland/ Shrubland	3	0	0	0	2	3	3	1	3	3	3	3
Cropland												
Natural Barren Land	0	0	0	0	0	0	0	0	3	3	2	3
Quarries/Mines	0	3	0	0	0	0	0	0	0	0	0	0
Developed Land	0	0	0	0	0	0	0	0	0	0	3	3
Riparian Areas	0	0	0	3	3	3	3	3	0	3	0	1
Open Water	0	0	0	3	0	0	0	3	0	3	1	3
Disturbed Land	2	0	0	0	0	0	0	0	0	0	0	0

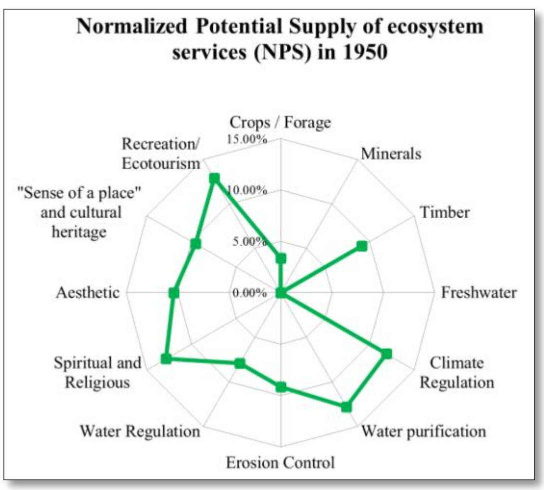


Figure 34. Potential supply of ecosystem services normalized by land cover area in the Black Hills National Forest in 1950 (calculated from Formula 4).

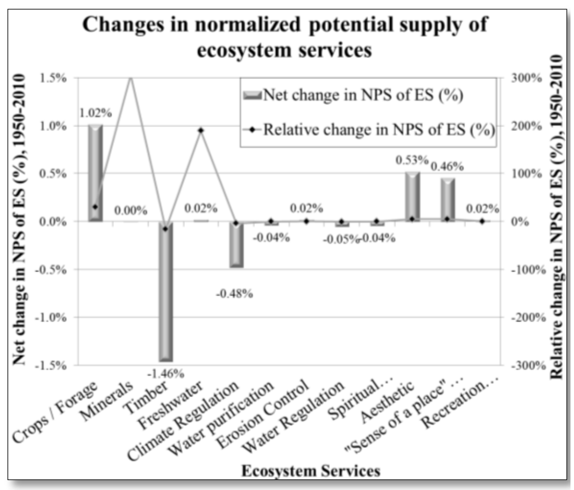


Figure 35. Changes in normalized potential supply of ecosystem services between 1950 and 2010 in the Black Hills National Forest.

4.3.2. Custer State Park

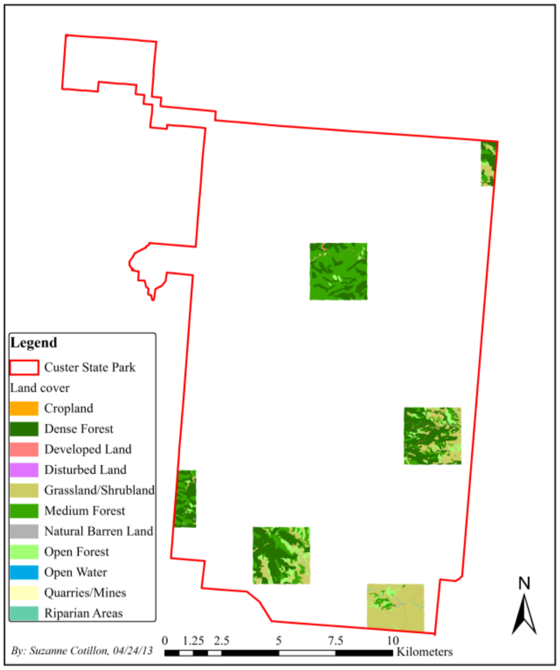
4.3.2.1. Description and Historical Background

Probably the most significant natural-cultural feature in the Black Hills is Custer State Park (CSP). Custer State Park is a place for both people and nature; visitors can see and experience much of the natural and cultural heritage of western South Dakota, while observing important wildlife. The park covers 28,500 hectares in the southeastern Black Hills and contains many of the most significant points of interest in the Black Hills such as the scenic Needles highway and the trailhead to Harney Peak. The park was created in 1919 through the efforts of a former governor of South Dakota and U.S Senator Peter Norbeck to create a sanctuary for wildlife (Hodgins and Sprague 1969; Walker 2013). Under the control of the Department of Game, Fish, and Parks of South Dakota, the park provides a recreation area for the local population and tourists from throughout the nation. Its purpose is to preserve and enhance scenery, wildlife, and other attractions such as the beautiful Sylvan Lake and several scenic roads. Although visitors come to CSP to see the buffalo herd that is the second largest in the United States (Hodgins and Sprague 1969), and to drive the Needles Highway (Pugsley 2012a), the main tourist concentration is in the campgrounds, picnic areas, resorts, and lodges. On average, 1.8 million visitors enter CSP every year. Moreover, every September, park managers organize a buffalo roundup to manage the size of the buffalo herd. This event has become an important tourist event and now attracts an average of 14,000 visitors from all around the world after the traditional tourism season ends. In 2012, the Great Plains Center for Ecotourism named CSP one of the top 50 ecotourism sites in the 10 state region. CSP and the Black Hills were two of the nine sites selected in South Dakota (Pugsley 2012a). In February 2013, Custer State Park was designated as one of the world’s top 10 wildlife destinations along with Yellowstone National Park, Wyoming, but also Costa Rica, and Namibia (Walker 2013). Indeed, the park’s ecosystems provide important wildlife biodiversity including elk, bighorn sheep, whitetail deer, mule deer, Merriam’s turkey, coyotes, nesting birds, raptors, cougars, and a variety of other mammals, amphibians, and reptiles (Walker 2013).

4.3.2.2. Land cover changes

Custer State Park is located in the Black Hills Limestone Plateau. Its main vegetation is forest, except in the southeastern part where grassland/shrubland is the dominant land cover. In 1950, the park land was covered by dense forest (34.1 percent), grassland/shrubland (29.5 percent), medium forest (28.1 percent), and open forest (7.2 percent). By 2010, 50 percent of the sampled area had changed (Figure 36, Figure 37, and Figure 38). These changes mainly occurred in the central and western sides of the park where forest was the dominant land cover. The main net land cover changes in CSP were the losses of dense forest (-11.5 percent) and medium forest (-7.9 percent), which balanced with the increases in open forest (+4.4 percent) and grassland/shrubland (+14.7 percent) (Figure 37). The area covered by dense forest declined because of its conversion to medium forest (8.5 percent of the total sampled area) and grassland/shrubland (7.8 percent of the total sampled area). The largest land cover conversion in CSP, however, was the change that occurred from medium forest to grassland/shrubland (12.9 percent of the total sampled area) (Figure 36 and Figure 38).

Land cover in sampled area of Custer State Park



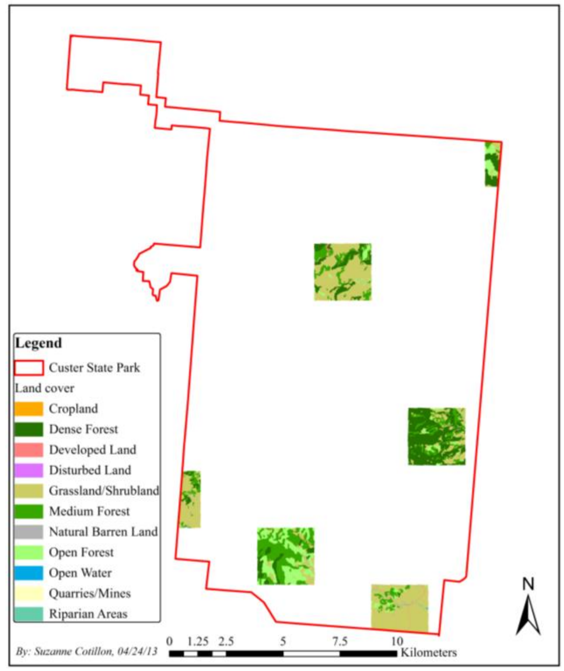


Figure 36. Custer State Park land cover maps in 1950 and 2010.

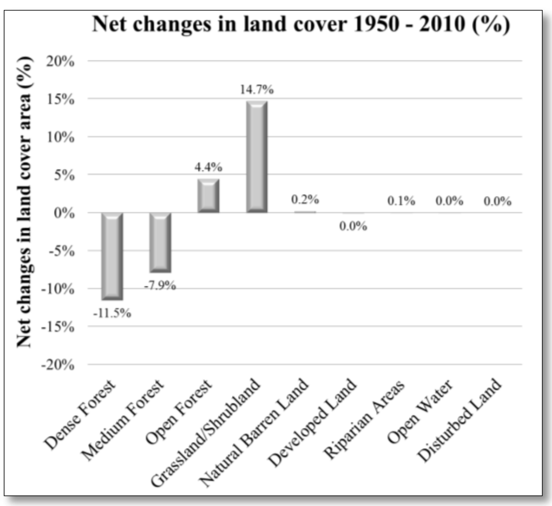


Figure 37. Net changes in land cover area between 1950 and 2010 in CSP. For example, the area covered by dense forest decreased 11.5 percent (from 34.1 percent to 22.6 percent) during the past 60 years.

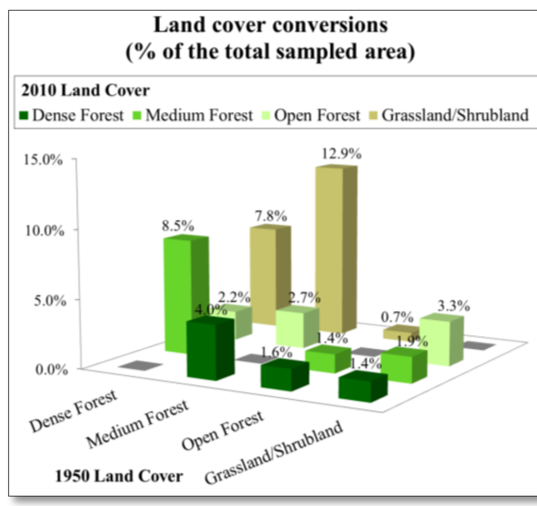


Figure 38. Main land cover conversions in CSP between 1950 and 2010. For example, 8.5 percent of the total sampled area in CSP switched from dense to medium forest, and 2.2 percent switched from dense to open forest.

4.3.2.3. Consequences of Land Cover Changes on Ecosystem Services Delivery

The park's management seeks to maintain a high level of productivity and biodiversity of the natural environment as well as preserving aesthetic, cultural, and geologic resources of the landscape (Walker et al. 1995). Custer State Park is managed first for recreation and then for production of timber. As a result, cultural services are the most supplied ES by the park's ecosystems followed by regulating services, such as erosion control and water purification (Table 7 and Figure 39). All together, they represent 90 percent of the total delivered services. Among the remaining services, forage production for wildlife is the most delivered in CSP. CSP forests also provided timber for commercial purposes but at a lower level than the Black Hills National Forest. As previously discussed, land cover conversions have direct and cumulative impacts on ecosystem services delivery. Land cover changes that occurred in Custer State Park between 1950 and 2010 decreased timber production, climate, and water regulation because of the loss of forested area (Figure 37 and Figure 38). On the other hand, the conversion from dense forest to open forest and grassland/shrubland had a positive impact on the delivery of many services, especially forage and freshwater provision, as well as cultural services such as aesthetic, cultural, and recreational values.

Table 7. Land cover classes and ecosystem services levels of production in Custer State Park. The justification for each index is given in Appendix D.

	PROVISIONING SERVICES				REGULATION SERVICES				CULTURAL SERVICES			
	Crops /Forage	*Minerals*	Timber	Fresh-water	Climate Regulation	Water purification	Erosion Control	Water Regulation	Spiritual/ Religious	Aesthetic	"Sense of a place"/ cultural heritage	Recreational
Dense Forest	0		2	0	3	3	3	2	3	2	2	3
Medium Forest	1		1	0	3	3	3	2	3	3	2	3
Open Forest	2		0	0	2	3	3	2	3	3	3	3
Grassland/ Shrubland	3		0	0	2	3	3	1	3	3	3	3
Cropland												
Natural Barren Land	0		0	0	0	0	0	0	3	3	2	3
Quarries/Mines												
Developed Land	0		0	0	0	0	0	0	0	0	3	3
Riparian Areas	0		0	3	3	3	3	3	0	3	0	1
Open Water	0		0	3	0	0	0	3	0	3	1	3
Disturbed Land	2		0	0	0	0	0	0	0	0	0	0

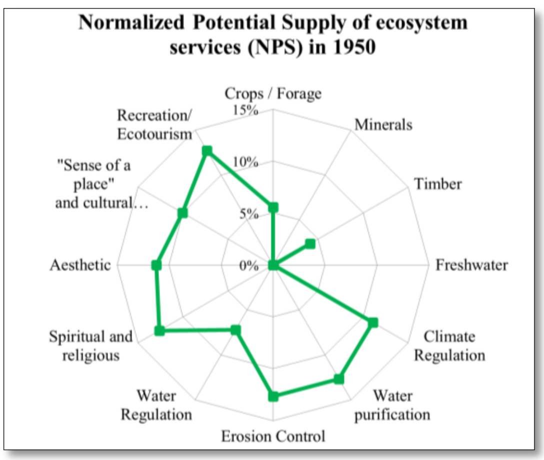


Figure 39. Potential supply of ecosystem services normalized by land cover area in CSP in 1950 calculated with Formula 4.

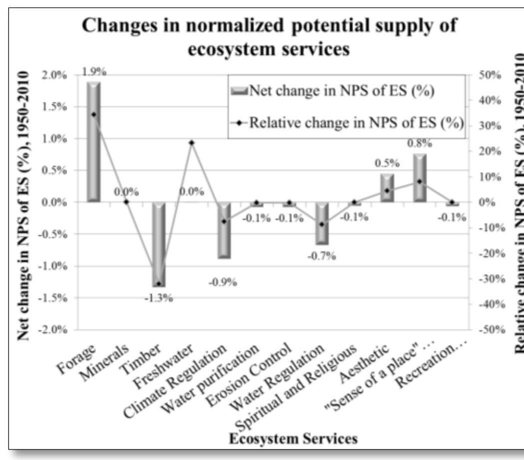


Figure 40. Changes in normalized potential supply of ecosystem services between 1950 and 2010 in CSP.

4.3.3. Wind Cave National Park

4.3.3.1. Description and Historical Background

Located in the southern Black Hills of South Dakota, Wind Cave National Park is bordered by the Black Hills National Forest on the west, Custer State Park on the north, and private lands on the east and south. Nearby communities include Hot Springs, and Custer, located within 10-15 miles of the park headquarters. The Pine Ridge Indian Reservation and Badlands National Park, which are visible from high points within Wind Cave National Park, lie some 20 miles east of the park boundary (Spence 2011).

Originally signed into law by President Theodore Roosevelt on 9 January 1903, the Act "To set apart certain lands in the State of South Dakota as a public park, to be known as the Wind Cave National Park" created the seventh national park in the United States. First devoted to the protection of a "cavern underlying … certain tracts, pieces, or parcels of land." Subsequent legislation enlarged the park and expanded its purpose to include the preservation and protection of subterranean and surface ecosystems as well as significant cultural and historical resources. In 1916, the creation of the National Park System allowed a common management for places of such national significance that justify special recognition and protection. The main purpose of the National Park Service lands is to preserve and promote natural or cultural resources for future generations. To these aims, extractive activities such as logging or mining are prohibited. The only uses of the lands are recreation and wildlife management.

Since the completion of the boundary fence in 1951, the park encompasses 13,740 hectares (34,000 acres) and is an important attraction in the Black Hills. It has drawn an average of 650,000 visitors annually for the past twenty years. Indeed, Wind Cave is one of the longest, oldest, and most complex rectilinear maze caves in the world (Komp 2011). Park management activities incorporate wildlife science and cave research to retain the park's natural resources and to provide visitors a quality experience (Wind Cave National Park 2011). WCNP was one of the earliest park areas to be designated a game preserve for the reintroduction of the American bison, and currently WCNP boasts one of the most genetically diverse and pure populations of bison in the nation (Komp 2011).

4.3.3.2. Land cover changes

Wind Cave National Park is located in the Black Hills Foothills sub-ecoregion, and thus is mainly covered by wide areas of grassland/shrubland with stands of ponderosa pine. Both in 1950 and in 2010, this land cover class represented about 70 percent of the park area, whereas forested land accounted for 27 percent (Figure 41). Forest land is located at higher elevations in the Black Hills Plateau on the western part of the park and grassland/shrubland are mostly at lower elevations in the Foothills. The remaining land is covered by natural barren land, which is mostly dry barren soils, and riparian areas along streams. Between 1950 and 2010, most land cover changes occurred within the forested area in the western part of the park. The net land cover changes in WCNP are the gain of dense forest (+1.6 percent of the sampled area), and the loss of medium forest (-1.4 percent) and grassland/shrubland (-0.6 percent). These net changes, however, do not reflect the numerous land cover conversions that occurred in the park during the past 60 years. The main land cover conversions were from medium forest to dense forest, open forest, and grassland/shrubland (6.2 percent of the sampled area) (Figure 43). Even though medium forest was converted to other land covers, some dense forest, open forest, and grassland/shrubland areas switched to medium forest (Figure 43). Because of this dynamic between ecosystems, the net land cover change between 1950 and 2010 in WCNP was small. This demonstrates the equilibrium that occurred because of land management, such as prescribed fires that aim to open the forest, and promoted natural vegetation succession.

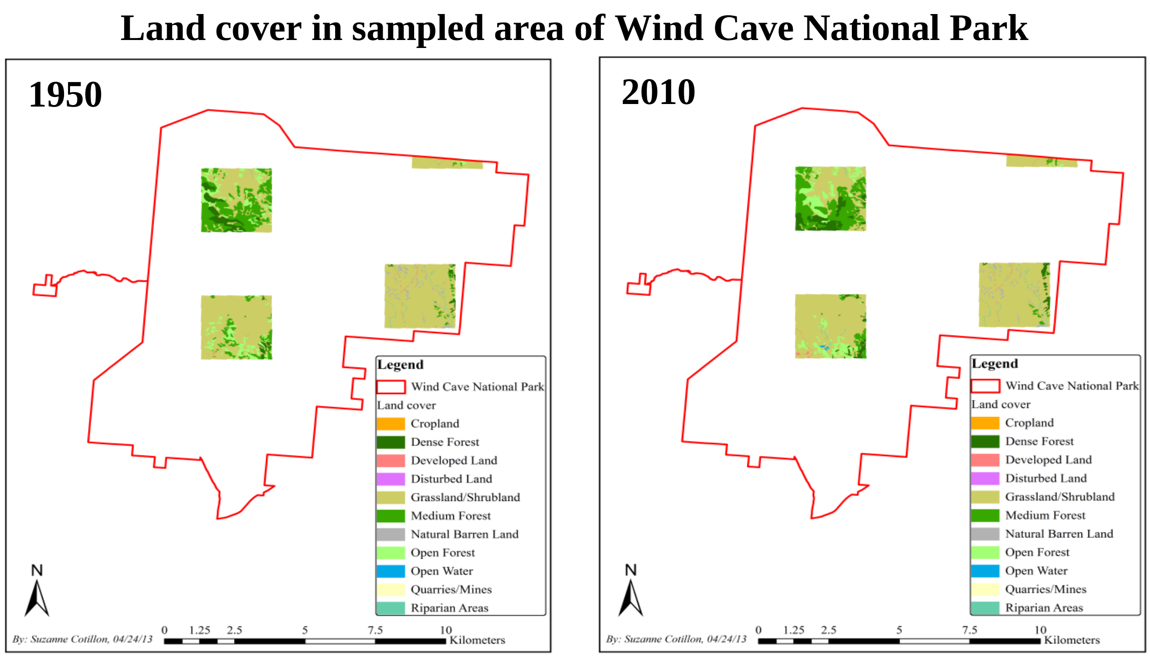


Figure 41. Wind Cave National Park land cover maps in 1950 and 2010.

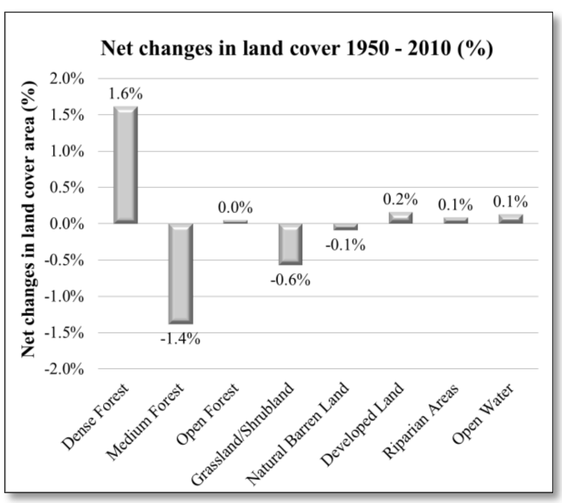


Figure 42. Net changes in land cover area between 1950 and 2010 in WCNP.

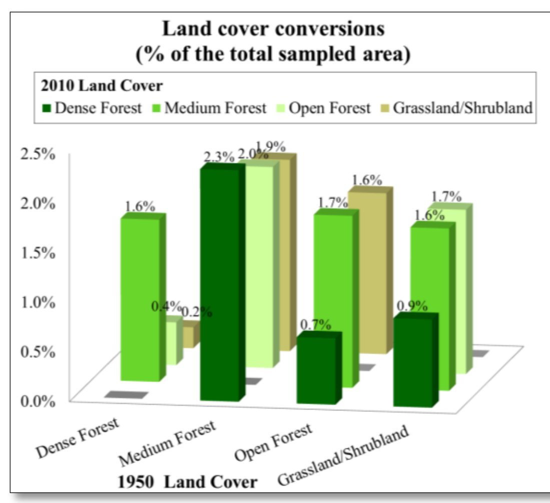


Figure 43. Main land cover conversions in WCNP between 1950 and 2010.

4.3.3.1. Consequences of Land Cover Changes on Ecosystem Services Delivery

Because there are no extraction activities on the National Park System land, provisioning services only consist of freshwater storage in WCNP. In contrast, regulating and cultural services are well provided by WCNP ecosystems (Figure 44 and Table 8).

In the park, ecosystem services are mostly provided by dense forest, medium forest, and grassland/shrubland, which are the dominant land cover classes in terms of area. Consequently, the most delivered services are spiritual and religious values, aesthetic value, recreation and ecotourism, and erosion control (Figure 44). The land within WCNP has historical, cultural, and spiritual meaning to many American Indians since the primary natural resource and the namesake of Wind Cave National Park is regarded as the place of creation for the Oglala Lakota (Spence 2011). Moreover, the Civilian Conservation Corps came to the park in 1934 to improve facilities and boost tourism in the area. Inside the cave, they helped sink a 208 foot elevator shaft, installed concrete steps and an indirect lighting system, repaired the cave trail, and began a cave survey. On the surface, they sloped banks for park roads, built a fence around the park to contain the wildlife, built fire trails, dug and constructed concrete reservoirs, erected or remodeled park buildings, landscaped the Headquarters area, and occasionally fought forest fires. The legacies of the CCC intervention in the park contribute to the cultural heritage and the recreational value of WCNP. Finally, the dominant grassland/shrubland vegetation helps reduce the erosion of the soil because of its dense root systems. As discussed in the previous part, land cover conversions in WCNP were numerous between 1950 and 2010 but resulted in minor net land cover changes (Figure 42 and Figure 43). These land cover conversions, however, directly affected ecosystem services provision by land cover classes (Figure 45). The grassland/shrubland class is the main producer of ES

Table 8. Land cover classes and ecosystem services levels of production in Wind Cave National Park. The justification for each index is given in Appendix D.

	PROVISIONING SERVICES				REGULATION SERVICES				CULTURAL SERVICES			
	Crops /Forage	*Minerals*	*Timber*	Fresh-water	Climate Regulation	Water purification	Erosion Control	Water Regulation	Spiritual/ Religious	Aesthetic	"Sense of a place"/ cultural heritage	Recreational
Dense Forest				0	3	3	3	2	3	2	2	2
Medium Forest				0	3	3	3	2	3	3	2	3
Open Forest				0	2	3	3	2	3	3	3	3
Grassland/ Shrubland				0	2	3	3	1	3	3	3	3
Cropland												
Natural Barren Land	0	0	0	0	0	0	0	0	0	1	0	0
Quarries/Mines												
Developed Land				0	0	0	0	0	0	0	3	3
Riparian Areas				3	3	3	3	3	0	3	0	1
Open Water				3	0	0	0	0	0	0	0	0
Disturbed Land				0	0	0	0	0	0	0	0	0

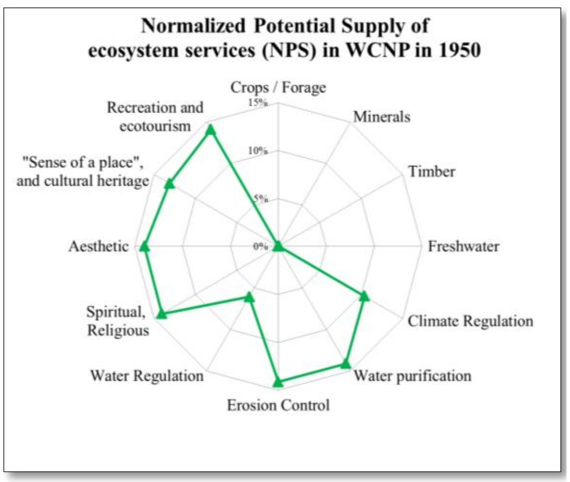


Figure 44. Potential supply of ecosystem services normalized by land cover area in WCNP in 1950 calculated with Formula 4.

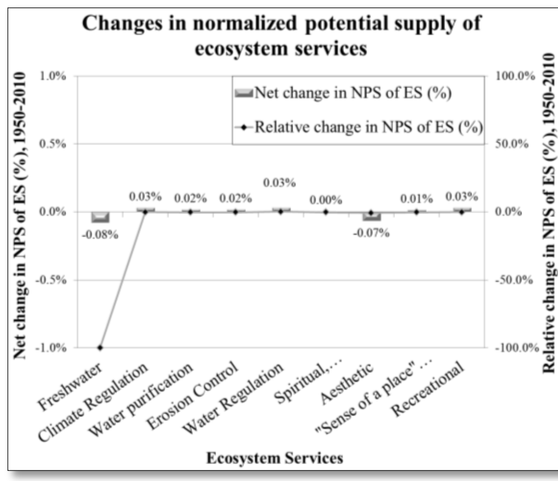


Figure 45. Changes in normalized potential supply of ecosystem services between 1950 and 2010 in WCNP.

in WCNP and its conversion to forested land is the principal cause of change in ecosystem services delivery in the park. Because the forest classes produce lower levels of water purification, aesthetic, “sense of place,” and recreational opportunities than the grassland/shrubland class, the changes in normalized potential supply is negative for these ecosystem services. On the other hand, the level of production of climate regulation service did not vary for the past 60 years because the various land cover conversions balanced the production of this ecosystem service from grassland/shrubland and medium forest to dense and open forests. Overall, changes in normalized potential supply of ecosystem services are low in WCNP because of the important ecosystems dynamics that contributed to the stability of the ecosystems services delivery over time.

4.4. Summary of the results

The three case studies, located within the ecoregion boundary, are influenced by a common climate, disturbances, and human interactions. They have the same overall vegetation, but in different proportions, and thus deliver comparable services. The initial potential supply of ES normalized by land cover area was primarily determined by the 1950 land cover classes distribution in each case study. In 1950, the delivery of cultural services by the case studies and the ecoregion landscapes was similar but the proportions of supplied regulating and provisioning services varied (Figure 46). WNCP land cover classes provided higher proportions of regulating services, and lower proportions of provisioning services than the entire ecoregion, CSP, or the BHNF. CSP landscape provided a lower level of provisioning services than the BHNF, but a higher level of erosion control.

Furthermore, the spatial distribution of land cover classes in the Black Hills were highly influenced by the physical geography of the ecoregion. Most of the land cover changes occurred in the core and the plateau, located at higher elevations and areas of steeper slopes, where dense forest is the dominant vegetation. At the ecoregion scale, land conversions led to a change in forest structure with more open stands of various

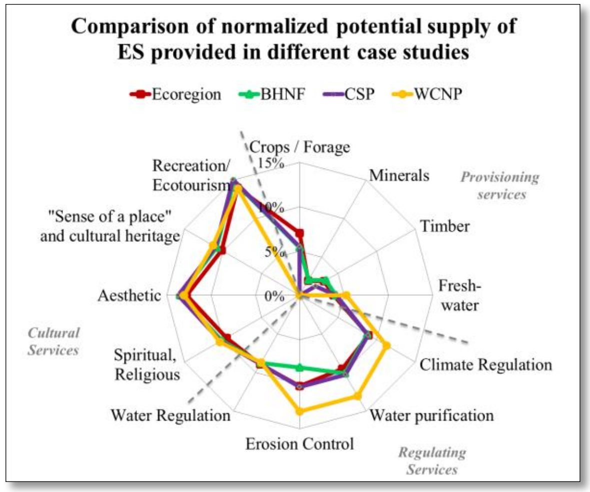


Figure 46. Comparison of ES supplied by the landscape of each case study and by the ecoregion as a whole in 1950.

sizes (Table 9). Consequently, the ecoregion delivered an overall lower level of services in 2010 than in 1950. This decrease in potential supply was mainly due to the reduction of timber production and climate regulation associated with the net loss of dense forest. The results in the BHNF and CSP were similar to the ecoregion trends but at a higher magnitude (Table 9). In CSP, the decrease in water regulation delivery was related to the net loss of medium forest, which is a particularity of this case study.

In contrast, in the foothills where the dominant vegetation was grassland/ shrubland, land cover changes were totally different. In the northern part of the foothills, there was an increase in developed land and cropland that contributed to the higher production level of crops/forage, “sense of place” and cultural heritage, and recreation/ecotourism value in the whole ecoregion (Table 9). In the southern foothills, such as in WCNP, net land cover changes were less significant. Overall, there was a small increase in dense forest and a slight decrease in grassland area. As a result, in WNCP, changes in ES delivery were minor and showed the importance of land cover changes dynamic (land conversions) to sustain ES delivery over time (Table 9).

Table 9. Summary of the net land cover changes, associated land cover conversions, and changes in ES delivery in the ecoregion and in each case study.

Ecoregion

NET LAND COVER CHANGES: Land cover	(%)
Dense Forest	-6.1%
Medium Forest	2.4%
Open Forest	4.8%
Grassland/Shrubland	-2.2%
Cropland	0.1%
Natural Barren Land	0.0%
Quarries/Mines	0.1%
Developed Land	0.7%
Riparian Areas	0.0%
Open Water	0.1%
Disturbed Land	0.3%

MAIN LAND COVER CONVERSIONS: Land cover in 1950 \ Land cover in 2010	Dense Forest	Medium Forest	Open Forest	Grassland/Shrubland	Cropland	Developed
Dense Forest	-	6.7%	4.7%	4.1%	0.0%	0.2%
Medium Forest	3.9%	-	2.7%	2.5%	0.0%	0.1%
Open Forest	1.6%	1.8%	-	0.8%	0.0%	0.0%
Grassland/Shrubland	4.1%	3.0%	1.7%	-	1.2%	0.5%
Cropland	0.0%	0.0%	0.0%	1.1%	-	0.1%

CHANGES IN ECOSYSTEM SERVICES DELIVERY	
Crops / Forage	0.32%
Minerals	0.01%
Timber	-0.54%
Freshwater	0.02%
Climate Regulation	-0.18%
Water purification	-0.05%
Erosion Control	-0.05%
Water Regulation	0.07%
Spiritual and Religious	-0.05%
Aesthetic	0.21%
"Sense of a place" and cultural heritage	0.19%
Recreation/Ecotourism	0.06%

BHNF

NET LAND COVER CHANGES: Land cover	(%)
Dense Forest	-12.7%
Medium Forest	2.0%
Open Forest	9.1%
Grassland/Shrubland	1.1%
Cropland	0.0%
Natural Barren Land	0.0%
Quarries/Mines	0.0%
Developed Land	0.3%
Riparian Areas	0.1%
Open Water	0.1%
Disturbed Land	0.6%

MAIN LAND COVER CONVERSIONS: Land cover in 1950 \ Land cover in 2010	Dense Forest	Medium Forest	Open Forest	Grassland/Shrubland	Cropland	Developed
Dense Forest	-	10.4%	8.5%	6.3%	-	0.2%
Medium Forest	5.0%	-	4.2%	3.2%	-	0.1%
Open Forest	2.4%	1.8%	-	0.8%	-	0.0%
Grassland/Shrubland	5.4%	2.2%	1.5%	-	-	0.1%
Cropland	-	-	-	-	-	-

CHANGES IN ECOSYSTEM SERVICES DELIVERY	
Crops / Forage	1.02%
Minerals	0.00%
Timber	-1.46%
Freshwater	0.02%
Climate Regulation	-0.48%
Water purification	-0.04%
Erosion Control	0.02%
Water Regulation	-0.05%
Spiritual and Religious	-0.04%
Aesthetic	0.53%
"Sense of a place" and cultural heritage	0.46%
Recreation/Ecotourism	0.02%

CSP

NET LAND COVER CHANGES: Land cover	(%)
Dense Forest	-11.5%
Medium Forest	-7.9%
Open Forest	4.4%
Grassland/Shrubland	14.7%
Cropland	0.2%
Natural Barren Land	0.0%
Quarries/Mines	0.1%
Developed Land	0.0%
Riparian Areas	0.0%
Open Water	0.0%
Disturbed Land	0.0%

MAIN LAND COVER CONVERSIONS: Land cover in 1950 \ Land cover in 2010	Dense Forest	Medium Forest	Open Forest	Grassland/Shrubland	Cropland	Developed
Dense Forest	-	8.5%	2.2%	7.8%	-	0.0%
Medium Forest	4.0%	-	2.7%	12.9%	-	0.0%
Open Forest	1.6%	1.4%	-	0.7%	-	0.0%
Grassland/Shrubland	1.4%	1.9%	3.3%	-	-	0.1%
Cropland	-	-	-	-	-	-

CHANGES IN ECOSYSTEM SERVICES DELIVERY	
Crops / Forage	1.89%
Minerals	0.00%
Timber	-1.32%
Freshwater	0.01%
Climate Regulation	-0.88%
Water purification	-0.07%
Erosion Control	-0.07%
Water Regulation	-0.66%
Spiritual and Religious	-0.05%
Aesthetic	0.45%
"Sense of a place" and cultural heritage	0.76%
Recreation/Ecotourism	-0.05%

WCNP

NET LAND COVER CHANGES: Land cover	(%)
Dense Forest	1.6%
Medium Forest	-1.4%
Open Forest	0.0%
Grassland/Shrubland	-0.6%
Cropland	0.0%
Natural Barren Land	-0.1%
Quarries/Mines	0.0%
Developed Land	0.2%
Riparian Areas	0.1%
Open Water	0.1%
Disturbed Land	0.0%

MAIN LAND COVER CONVERSIONS: Land cover in 1950 \ Land cover in 2010	Dense Forest	Medium Forest	Open Forest	Grassland/Shrubland	Cropland	Developed
Dense Forest	-	1.6%	0.4%	0.2%	-	0.0%
Medium Forest	2.3%	-	2.0%	1.9%	-	0.0%
Open Forest	0.7%	1.7%	-	1.6%	-	0.0%
Grassland/Shrubland	0.9%	1.6%	1.7%	-	-	0.2%
Cropland	-	-	-	-	-	-

CHANGES IN ECOSYSTEM SERVICES DELIVERY	
Crops / Forage	-
Minerals	-
Timber	-
Freshwater	-0.08%
Climate Regulation	0.03%
Water purification	0.02%
Erosion Control	0.02%
Water Regulation	0.03%
Spiritual and Religious	0.00%
Aesthetic	-0.07%
"Sense of a place" and cultural heritage	0.01%
Recreation/Ecotourism	0.03%

CHAPTER 5. DISCUSSION

5.1. Land Cover Change Drivers between the 1950s and 2010s

5.1.1. Fire

Historically, fire was a keystone ecological process that shaped the composition and structure of plant communities in the Black Hills, thinned the forest, and prevented broad-scale expansion of pine trees into adjacent prairies. Ponderosa pine is a fire-adapted species, needing periodic low-intensity fires to consume small seedlings, concentrations of woody fuels on the forest floor, and prune lower branches from large trees (Boyte 2009; Shepperd and Battaglia 2002). Prior to settlement, the fire frequency was about 3-9 years for the prairie and 10-25 years for the pines (National Park Service 2013). The result in the landscape was a mosaic of different stand ages and forest structures, with conditions ranging from openings, to groups of young seedlings, to clumps and groups of older trees, including large orange-barked patriarchs. This forest mosaic represented healthier forests than those dominated by even-aged stands.

Over the past 100 years, however, fire has been suppressed throughout all United States' forests due to a combination of circumstances and a misunderstanding of the significance of fire. As a result, forest density has changed markedly in the Black Hills. Because of fire suppression, forest litter built up, permitted the development of many more younger stands of even-aged trees, and increased the fuel load leading to more frequent large stand-replacing fires due to human and natural causes (lightning) (Raventon 1994; Shepperd and Battaglia 2002). Since 1985, the trend of Black Hills fires in terms of frequency, intensity, and size has dramatically risen (Raventon 1994, 135) (Figure 47 and Figure 48).

Fires occurred mostly in the southern Black Hills - where the climate is warmer and drier - and affected land cover change in two ways during the study period. First, fires that occurred before 1950 changed the state of the environment and thus influenced the ecosystem services provided by the Black Hills landscape in 1950. Indeed, fires in the 1930s and 1940s burned the existing forest and extended grassland/shrubland areas (USDA 2009). Consequently, there was a noticeable regrowth of dense and medium forests from these grassland/shrubland areas between 1950 and 2010 (21.3 percent of the total conversion from grassland/shrubland to dense forest was related to fire prior to 1950) (Figure 49). Overall, 3.1 percent of the total land cover change in the ecoregion was affected by these past fires. Second, fires that occurred between 1950 and 2010 were responsible for 9.4 percent of the total land cover change in the Black Hills ecoregion. The resulting net land cover changes were the loss of dense forest and medium forest, and consequently an increase in grassland/shrubland area (Figure 49). Indeed, 38.0 percent of the total conversion from dense forest to grassland/shrubland in the ecoregion was caused by fire (respectively 41.2 percent of the conversion of medium forest to grassland/shrubland). Moreover, fire also allowed the opening of some riparian areas and natural barren land that were previously covered by forests (Figure 49).

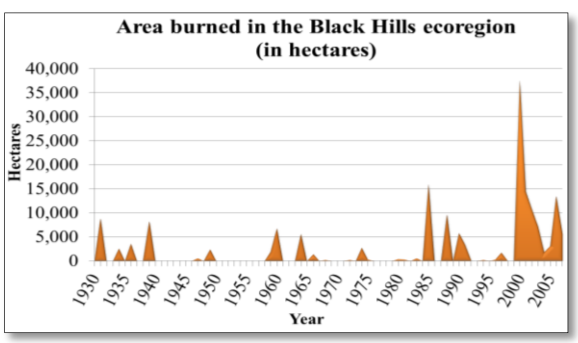


Figure 47. Number of hectares burned every year in the Black Hills from 1930 to 2009 (USDA 2009).

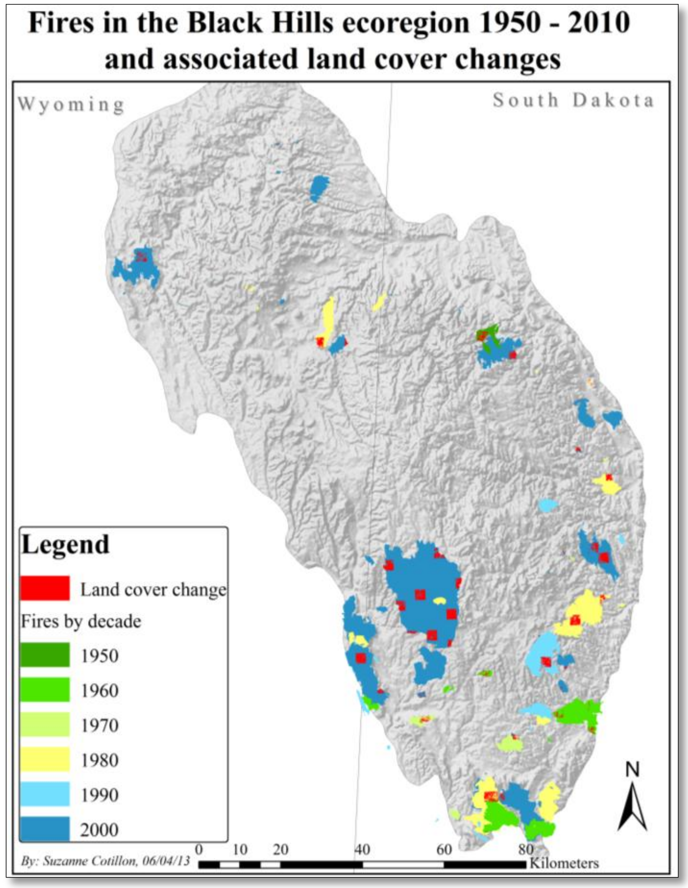


Figure 48. Map of post-1950 fires in the Black Hills ecoregion and associated land cover changes in sampled area (data from USDA 2009).

Land cover conversions associated with fires (% of the total land cover conversions)

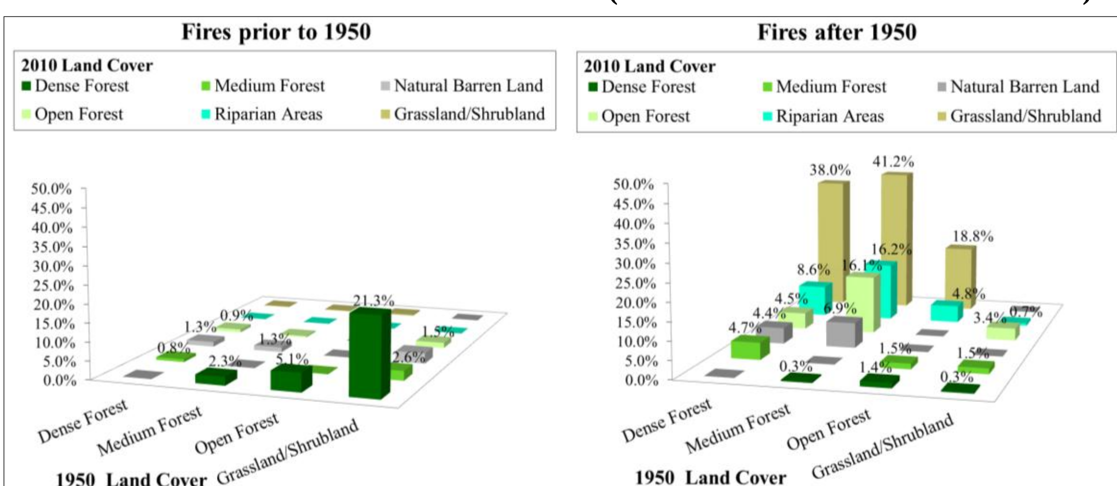


Figure 49. Land cover conversions associated with fires before and after 1950 in the ecoregion. For example, 38 percent of the total conversion from dense forest to grassland/shrubland was because of fires that occurred after 1950 in the ecoregion.

5.1.2. Commercial Logging

In the Black Hills, there are currently 22 firms involved in processing forest products, distributing and selling forest products, or using forest products to manufacture secondary products. Thirteen firms are primary producers, firms that directly process raw logs purchased from the Black Hills National Forest, other agencies and private landowners, nine of which are sawmills. Nine firms are secondary producers that process sawn timber or mill residue (*i.e.*, cants, wood chips, pellets) (USDA 2005). Timber production for commercial purposes mainly occurs in the National Forest (Figure 50).

The results of land cover changes from the BHNF shows an important net decrease of dense forest (-12.7 percent of the total sampled area) (*cf.* 4.3.1.1.). Since 1964[7], 329,705 hectares (65 percent of the BHNF) have been harvested for timber sales and some parcels have been harvested several times. Most of the areas harvested in the period 1960-1970 and 1970-1980 were harvested again in a later decade (Figure 51). More than 60 percent of the area harvested in 2000-2010 had been harvested in the previous 50 years. Therefore, the resulting land cover change visible in 2010 is the cumulative impact of these multiple harvests over the study period. Whereas the total harvested area decreased after 2000, the number of timber sales tended to steadily increase (Figure 51 and Figure 52). The size of harvested parcels, however, greatly decreased from an average of 140 hectares to 24 hectares after 1964 (Figure 52). This change in logging practices may have had various consequences on land cover changes and ecosystem services delivery and will be further discussed in part 5.2.1. Timber harvests were responsible for 29.4 percent of the total change in the ecoregion throughout the study period. Like fire, logging impacted land cover changes in two ways

[7] Timber sales data from the BHNF starts in 1964.

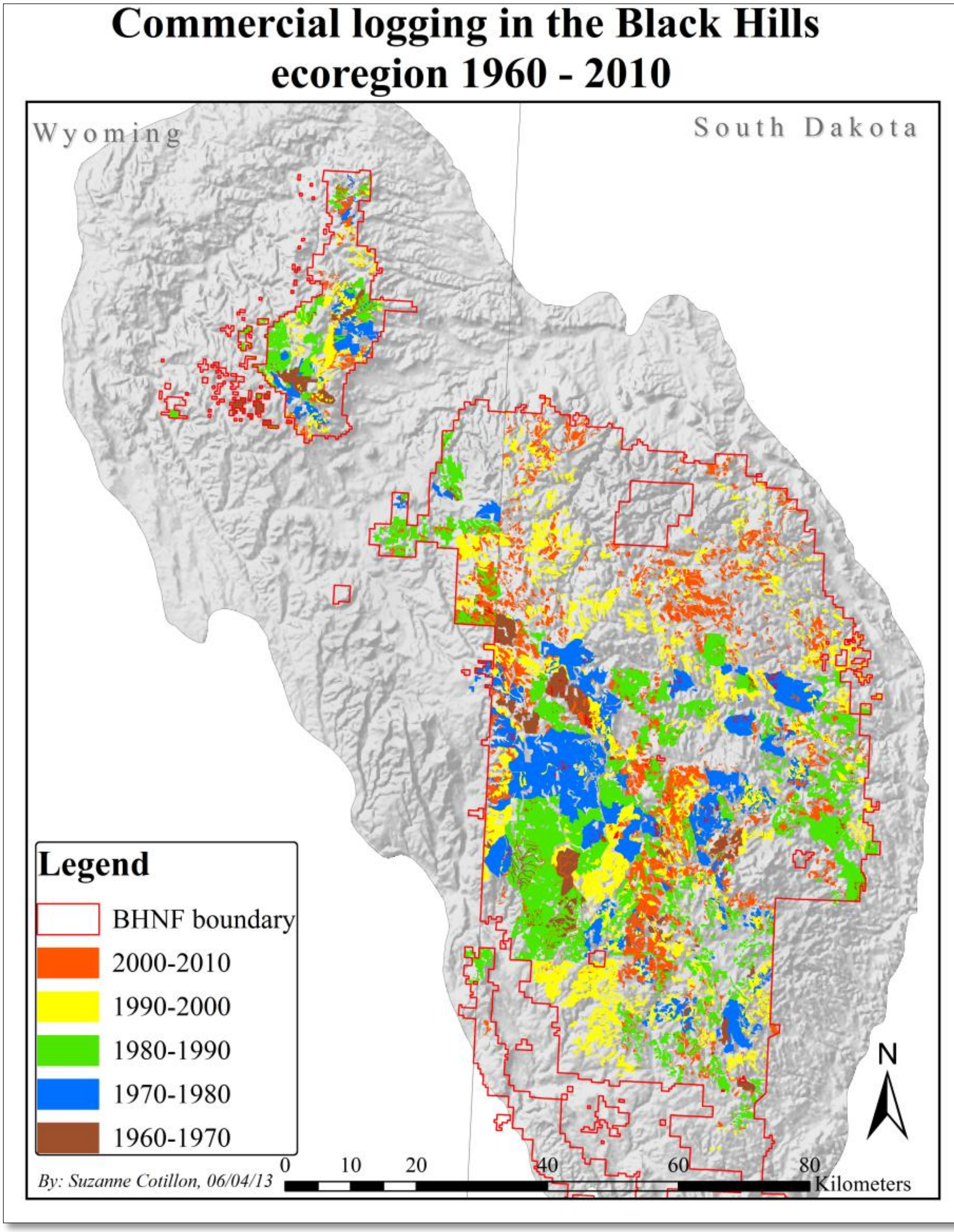


Figure 50. Map of harvested areas in the Black Hills National Forest (data from USDA 2012b).

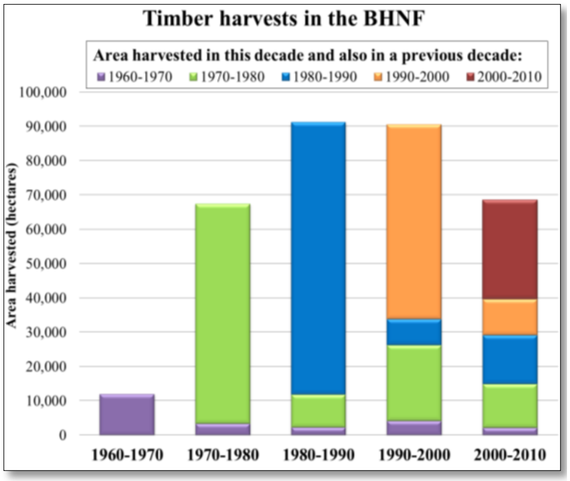


Figure 51. Timber harvests in the BHNF for the past 50 years (data from Black Hills National Forest 2011). For instance, 10,000 hectares of the area harvested during 1980-1990 were previously harvested in 1970-1980. The 1960-1970 period starts in 1964.

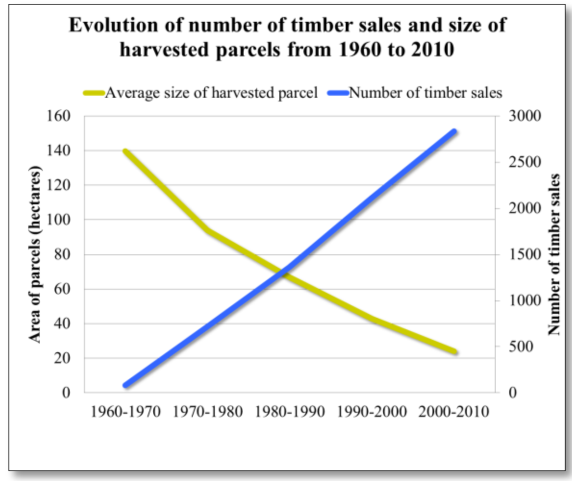


Figure 52. Number and size of harvested parcels from 1960 to 2010 (data from Black Hills National Forest 2011).

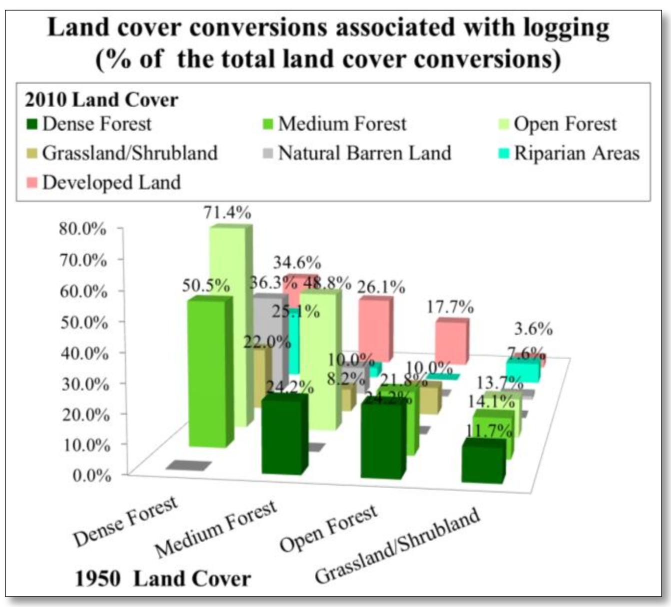


Figure 53. Land cover conversions on harvested areas in the ecoregion. For example, 50.5 percent of the total conversion from dense forest to medium forest in the ecoregion was associated with logging. To avoid double-counting of land cover changes, only harvested area outside of fire boundaries has been considered.

(Figure 53). On one hand, it switched forest structure from dense stands to more medium and open stands. On the other hand, forest regrowth was visible on harvested areas that have not been harvested in the past 20 or 30 years. Logging was also associated with the uncovering of natural barren land or riparian areas covered by forest in 1950, and the construction of new roads (*i.e.,* developed land) in the forest (Figure 53).

Timber harvest also occurred in Custer State Park, but the data needed to evaluate the direct impact of logging on land cover changes were not available, and thus it is not considered in this part.

5.1.3. Increase in demand for recreation and ecotourism

Population plays a major role in the use of recreational resources. As population increases, so does the demand for recreational resources (Zinser 1995). Population growth has also a direct impact on land cover changes. In the Black Hills ecoregion, developed land increased 0.74 percent in the ecoregion between 1950 and 2010, which is equivalent to an increase in 917 hectares or a relative change of +199 percent (*cf.* Figure 23 in part 4.1.1.). The development of developed areas occurred not only in the transportation corridor in the foothills but everywhere in the ecoregion, and demonstrated the attractiveness of the region for the local and regional populations. In the Black Hills, whereas population has doubled between 1950 and 2010 (+103 percent), the number of visitors in Mount Rushmore National Memorial, which is a nationally recognized monument, increased 215 percent (Figure 54 and Figure 55). Moreover, Custer State Park, Wind Cave National Park, as well as other attractions, such as Jewel Cave, Devils' Tower National Monument, and Mount Rushmore National Memorial, provide many recreational opportunities and draw most of the national and international visitors to the Black Hills (Julin 2009) (Figure 55). In addition, the natural attributes of the ecoregion, for instance the forests, the streams, the granitic needles, and the caves, offer a suitable setting for recreational uses.

After the work of the Civilian Conservation Corps in 1933 to improve outdoor recreation on public lands, the reputation of the Black Hills as a recreational center grew steadily. All these sights and experiences were designed specifically for the enjoyment of motoring tourists (Julin 2009). The footprints of the Civilian Conservation Corps are still visible in the landscape today where they continue to enrich the cultural and historical values of the Black Hills (Sanders 2004; USDA 1996a). The BHNF provides major recreation areas with the forest and its natural features, but also accommodations such as campgrounds, lodging sites, and summer homes (USDA 2012c). Several Black Hills towns, such as Custer, Hill City, and Rapid City, have grown rapidly and developed

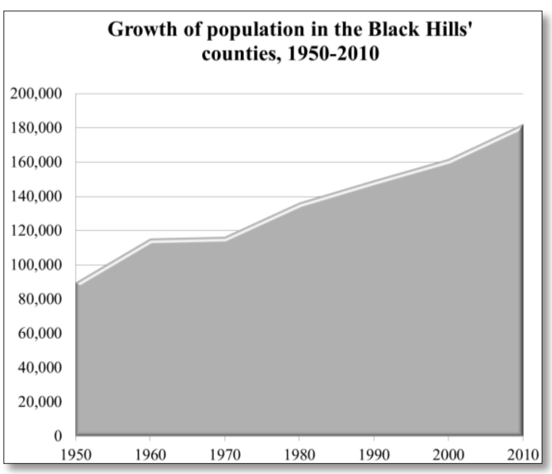


Figure 54. Evolution of the total population in the 7 counties of the Black Hills ecoregion (data from Forstall 1995; Olson, Moss, and Arwood 2008).

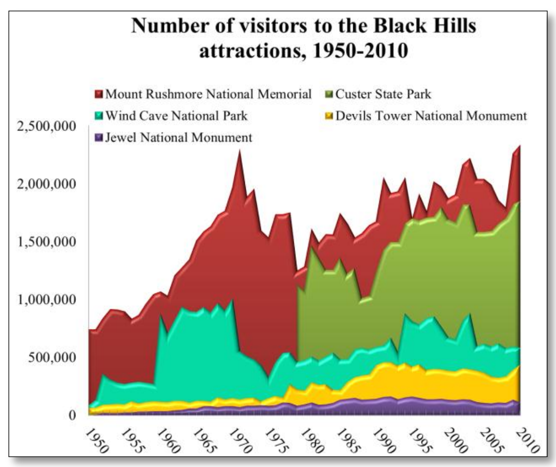


Figure 55. Evolution of number of visitors in the main Black Hills attractions (data from National Park Service 2012; Pugsley 2012b). The data obtained for CSP are based on traffic counts and only started in 1979.

many hotels, motels, and attractions to enhance tourism opportunities.

Although the land cover analysis did not capture any major land cover changes that resulted directly from the increase of tourism demand in the area since 1950, some patterns of ownership and modifications in the policies and regulations have drastically influenced recreational patterns. During the environmental movement of the 1960s and 1970s, major interest evolved for amenity resources and caused a tremendous increase in recreational use of public lands. In 1970, there were 1.8 million visitor-days recorded in the BHNF (Cliff 1970) and by 1989 this number had increased to 2.7 million (Robertson 1989). A survey led by the Forest Service estimated an average number of 1.2 million visitors each year between 2005 and 2009 in the National Forest and the associated Black Elk Wilderness area (USDA 2012c). This report shows that visitors mostly come to the national forest to view natural features, drive around, or to enjoy outdoor activities, such as fishing and hiking (USDA 2012c) (Figure 56). Consequently, the increase in demand for recreation and ecotourism acted as an indirect driver of change and influenced land management toward preserving the quality of the natural landscape while promoting recreational use.

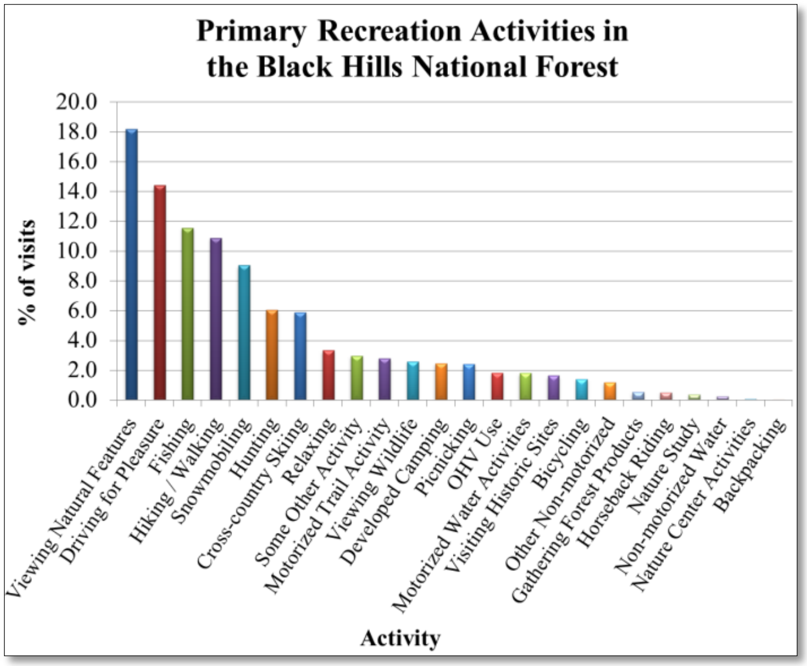


Figure 56. Main visitors' activities in the Black Hills National Forest between 2005 and 2009 (USDA 2012c).

5.1.4. Summary of land cover change drivers

Drivers can have direct and indirect effects on land cover changes. The three major land cover changes drivers analyzed in this study were fire, logging – direct drivers –, and the increase in recreation and tourism demand – an indirect driver. Direct drivers explained most of the land conversions that occurred between the major land cover classes (Table 10). Fires switched part of the 1950 forest to grassland/ shrubland whereas logging changed its structure and composition by increasing medium and open forest stands across the landscape. Moreover, some natural barren lands and riparian areas that were covered by forest in 1950 became visible in 2010 after logging activities. Forest management also required the construction of new roads to access harvested areas, which contributed to the conversion from dense and medium forests to developed land associated with logging. The conversions from forests to developed land can also be associated with the expansion of infrastructure to respond to the recreation and tourism demand. Fire, logging, and recreation/tourism, however, poorly explained the minor land conversions that occurred in the ecoregion, especially in the foothills, such as the increase of developed land and cropland areas (*cf.* Figure 24 in part 4.1.1.).

Table 10. Percent of the major land conversions associated with the direct drivers of land cover changes in the Black Hills ecoregion. For instance, fire and logging are responsible for 77 percent of the total conversion from dense to open forest between 1950 to 2010. The fire category considers fires that occurred both before and after 1950.

		2010 Land Cover						
1950 Land Cover	**Drivers**	**Dense Forest**	**Medium Forest**	**Open Forest**	**Grassland/ Shrubland**	**Natural Barren Land**	**Developed Land**	**Riparian Areas**
Dense forest	Fire		5%	5%	38%	6%	4%	9%
	Logging BHNF		50%	71%	22%	36%	35%	25%
	Total		**56%**	**77%**	**60%**	**42%**	**39%**	**34%**
Medium forest	Fire	3%		16%	41%	8%	4%	16%
	Logging BHNF	24%		49%	8%	10%	26%	4%
	Total	**27%**		**65%**	**50%**	**18%**	**30%**	**20%**
Open forest	Fire	6%	2%		19%	-	5%	5%
	Logging BHNF	24%	22%		10%	-	18%	-
	Total	**30%**	**23%**		**29%**	**0%**	**23%**	**5%**
Grassland/ Shrubland	Fire	22%	4%	5%		3%	1%	1%
	Logging BHNF	12%	14%	14%		1%	4%	8%
	Total	**33%**	**18%**	**19%**		**4%**	**4%**	**8%**

5.2. Influence of land management on ecosystem services delivery

There is great variation in the degree to which public and private lands are managed for long-term biodiversity conservation and ecosystem services in the Black Hills ecoregion. This part aims to correlate the past management policies in each case study to the changes in ecosystem services delivery by the landscape in order to determine whether the developed methodology reflects management differences. Land cover change on private land is also analyzed to identify trends of land management by private owners.

5.2.1. BHNF: A land of multiple-uses focused on conservation management

The Black Hills National Forest is managed as a multiple-uses land according to the conservation principle, defined by Aldo Leopold as " A state of harmony between people and land" (USDA 1996a). As discussed before, the BHNF underwent an important change of structure following the fire suppression policy established by the Forest Service. Fire suppression greatly enhanced timber production and had a drastic impact on forest management in the Black Hills. In this part, the discussion will focus on the management directions related to the drivers of land cover changes described in the previous section.

Since the settlement period, timber production has been the dominant use of the forest. The Black Hills National Forest had grown from 1.5 billion board feet (bbf) of merchantable timber in 1899 to 2.96 bbf in 1948, at which time the annual cut stood at 40 million board feet (mmbf). About1956 the silvicultural system used in the Black Hills changed from single-tree selection to shelterwood. The shelterwood system[8], typically two-stage, has been used up to the present and proven to be most reliable in managing these forests (Ball and Schaefer 2000; Shepperd and Battaglia 2002). In a two-cut shelterwood, basal areas are generally reduced below 14 m^2 per hectare (60 ft^2 per acre) in an initial seed cut using a marking regime that leaves a uniform canopy of the biggest and healthiest trees for a seed source (Figure 57). Abundant regeneration is usually produced within 5 to 10 years. The overstory can be removed anytime once a new generation of trees is established. In practice, some residual overstory trees are left for wildlife habitat, snag recruitment, and other purposes (Shepperd and Battaglia 2002, 70).

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[8] A silvicultural system in which overstory trees are removed in a series of cuts designed to achieve a new, even-aged stand under the shelter of remaining trees.

Recently, additional silvicultural treatments have included intermediate thinning, regeneration harvest, patch clear-cutting for wildlife openings (Figure 58), pine encroachment removal, hardwood restoration, group selection, prescribed burning, and precommercial thinning to control forest density, wildlife, and insect attacks (Ball 2005; Shepperd and Battaglia 2002). Prescribed fire, which can only improve the present condition of the forest, has not been used to a great extent to control regeneration in the Black Hills and should be used more frequently as one of many tools to manage pine ecosystems (Shepperd and Battaglia 2002, 82).

Following the demand for timber resulting from the rapid economic and population growth after World War II, timber harvesting increased 120 percent from 1950 to 1970, and 87 percent from 1970 to 1990 in the BHNF (Figure 59). In the early 1990s, however, the rise of market prices associated with a national decrease in timber supply, changes in National Forest land management, increase in environmental concerns for natural resources on public land, and land reservation for.

Figure 57. An even-aged ponderosa pine stand (Picture took in 2012).

Figure 58. A patch clearcut in the middle of a dense forest. Clearcutting provides some openings and forage for livestock and wildlife (Picture took in 2012).

wilderness, resulted in a decline of timber sales in National Forests (Fedkiw 1998; Fiacco 2010; Thoreau Institute 2006). In the Black Hills, timber cuts dropped 51 percent between 1990 and 2005 (Figure 59).

The Black Hills National Forest, historically used heavily for timber, now is supporting increased recreation, wildlife, water, and other uses according to the Multiple-Use Sustained-Yield Act of 1960. The first Forest Management Plan of the Black Hills was developed in the early 1980s and described the management directions for the following 10 years (USDA 1983). The goals defined by the Forest Plan varied by management areas. The BHNF is divided into twenty different management categories that have their own management directions. The overall management, however, aimed to improve and maintain wood production, water yield, and forage production, while providing other commercial products, visual quality, diversity of wildlife habitat, recreation opportunities, and a variety of goods and services (USDA 1996b).

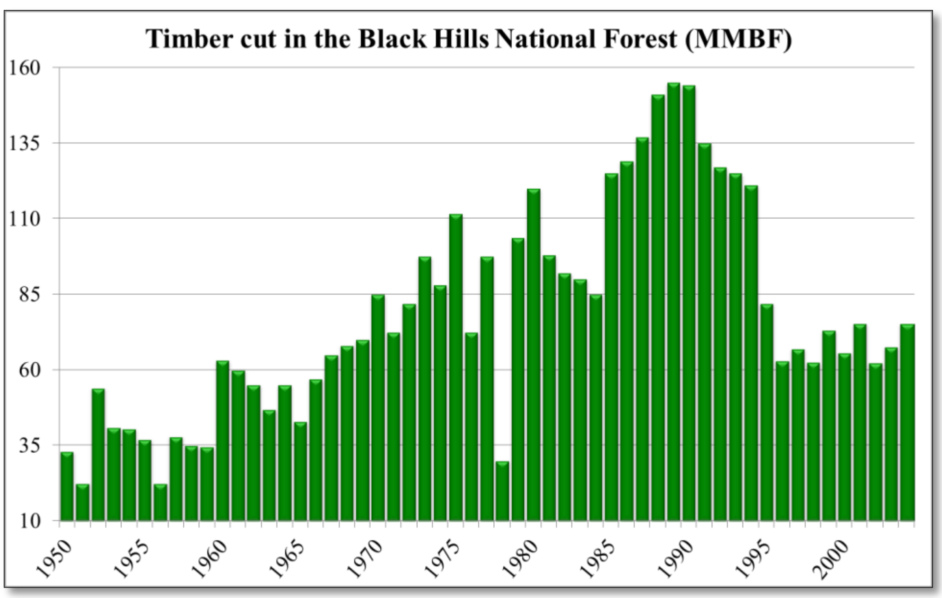


*Figure 59. Timber cuts in the Black Hills National Forest, 1915 through 2005 (USDA 1996a; USDA 2012b). *In 1976, the fiscal year used by the Forest Service changed. For that reason, 1976 represents a transition year and includes only four months' worth of volume cut.*

Land cover change that took place in the BHNF over the past 60 years was easily explained by the results of forest management. Indeed, in the BHNF, 51.4 percent of the total land cover change occurred in harvested areas and resulted in the creation of more open stands (medium and open forests). Moreover, modern forestry practices are providing more timber from less area (Sedjo 2008). The number of sales increased while the volume of timber cuts[9] and the size of harvested parcels declined to reduce the impacts on aesthetics, wildlife, habitat, watershed, and endangered species (USDA 2005) (*cf.* Figure 52 in part 5.1.2.). As in the ecoregion as a whole, the remaining changes in the BHNF are mostly associated with fire (loss of forested area) and urbanization (increase in developed land).

The BHNF management system has many different objectives, and associated actions, for each of the multiple uses. The consequences for ES delivery, however, are related to the cumulative impact of all management actions on ecosystems. The Forest Service has the authority to control the intensity of grazing in accordance with multiple-use goals and in order to maintain the productivity of grassland. The Black Hills National Forest currently provides approximately 466 million pounds of forage per year (USDA 1996b). Approximately 25 percent, (127 million pounds of forage, or 128,000 animal unit months (AUMs)), is available for livestock. The remaining 75 percent of forage is reserved for wildlife, plant health, regrowth, and soil and watershed needs. The increase in forage production (*cf.* Figure 35 in part 4.3.1.2.) is the direct consequence of the opening of forest stands by forest management to promote understory production for wildlife and livestock. Aesthetic and cultural values, as well as recreation and

[9] The volume of timber cuts have leveled off since 1995 (Figure 59).

ecotourism in the BHNF, also benefited from the increase in open and medium forest area.

5.2.2. CSP: Land management for nature and people

"In Custer State Park, we manage all the resources, even visitors" (Brundige 2012). As a place for both nature and people, the current management mission of the park is "To manage and protect the renewable natural resources of CSP including forestland, rangeland, buffalo herd, wildlife herds, and fisheries. Management emphasis is on the production of an approximate mix of products compatible with a multiple-use approach." To this aim, the broad objectives of the park are to manage and protect the park's natural, cultural, geological resources, and develop and promote the park to its potential as a tourism destination for South Dakota (Walker et al. 1995).

Therefore, the Resource Management Plan 1995 – 2010 of CSP emphasizes range, forest, fire, and wildlife management. The plan action steps seek to maintain these natural systems or in some cases move them toward a higher level of productivity and biodiversity to assure system health, viability, and profitability, while preserving all the resources and aesthetic qualities of the landscapes. The key management directions aim to (1) reduce pine encroachment with logging and fire on rangeland, (2) restore the historic fire frequencies (from 13 to 21 years) through prescribed burns, (3) enhance productivity and diversity, and (4) simulate the effects of natural disturbances on forested land using forestry tools (Walker et al. 1995, xvi-xviii).

To complete these objectives, the habitat management tools comprise prescribed fires and timber harvesting. Fire use concentrates on prescribed burning as a tool to reduce risk (fuel reduction). Timber management strived to enhance the forest understory, forage production, and to provide for maximal habitat diversity for wildlife. To achieve these results, CSP manages forest stands at a lower density than the BHNF (basal area < $14m^2$ per hectare) (Brundige 2012).

From 1950 to 2010, fire was an important driver of change in CSP. Large fires of 1988 (Galena fire) and 1990 (Cicero Peak), resulting from previous fire suppression, caused a loss of hiding cover (dense forest) but also tremendously increased forage production for wildlife (Figure 60 and Figure 61). These fires accounted for 56 percent of the total land cover change in CSP throughout the study period and for almost the totality of the increase in grassland/shrubland area (Figure 61). Another driver of change related to land management is logging. From 1951-1970, the park experienced the beginnings of forest management; both in the form of timber harvest and timber stand investment. From 1980 to 1995 the park pursued an aggressive timber management effort (1,910 hectares have been treated though timber harvest and non-commercial thinning) (Walker et al. 1995). Non-commercial thinning included extensive thinning designed to develop understory vegetation. The predictions of the 1995 management plan showed the harvest and thinning strategy mainly in the northwest and southeast areas of CSP (Figure 62). The predicted conifer density map correlated with the land cover conversions in CSP where there are more open and medium forests (low and medium forest canopy) in the south because of the harvest and thinning efforts, and denser forest on the northern and eastern part of the park that have not been managed yet (Figure 60 and Figure 62). This correlation confirms that timber harvest was the second driver of land cover changes in CSP between 1950 and 2010. Recreation, however, was

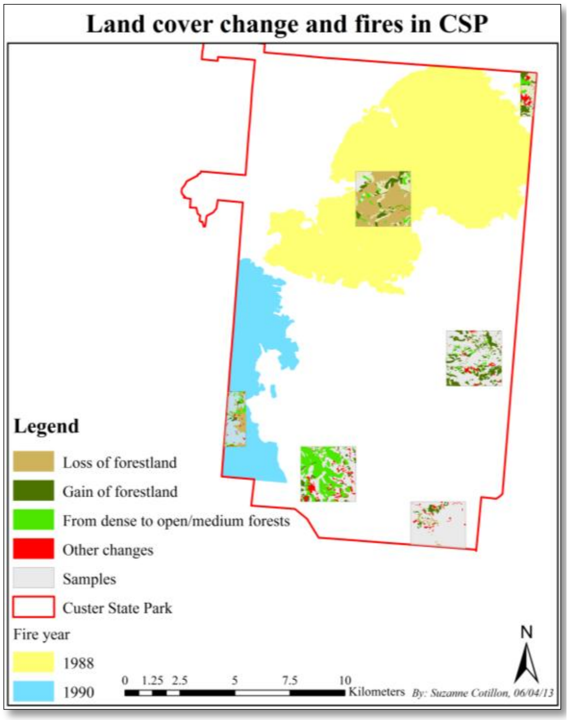


Figure 60. Fires and land cover conversions in sampled areas between 1950 and 2010 in CSP.

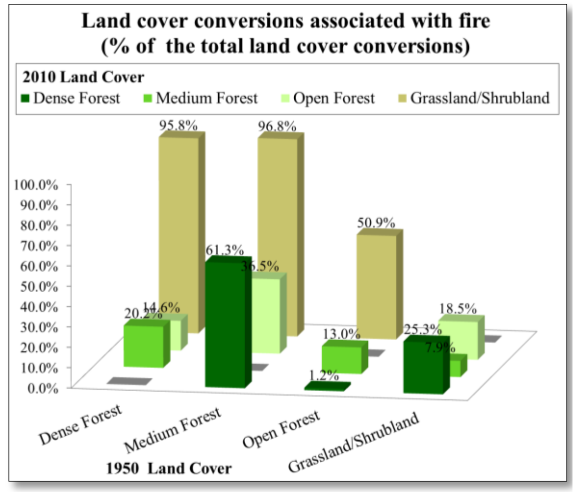


Figure 61. Land cover conversions resulting from the Galena and the Cicero Peak fires in CSP.

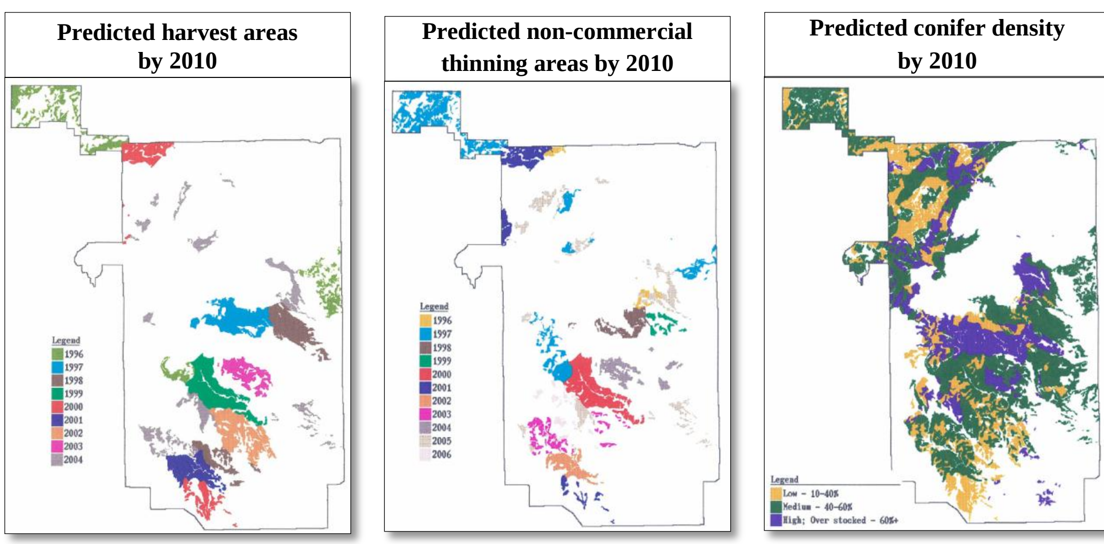


Figure 62. Prediction maps from the Resource Management Plan 1995-2010 of CSP (Walker et al. 1995).

also a driver of change and one very important aspect of the wildlife in CSP. Recreational opportunities include hunting[10], hiking, touring, and scenery. To respond to the increased demand for recreation/ecotourism, managers promoted public education and awareness of the diverse cultural legacy of CSP, and encouraged multiple uses recreation opportunities for park visitors. Visitor numbers in the park increased 64 percent after 1979 and demonstrated the success of the park promotion for the past 30 years (*cf.* Figure 55 in 5.1.3.).

The results of land management were apparent in the change of ES delivery since 1950 in CSP. As planned by managers, forage production greatly increased in the park (*cf.* Figure 40. Changes in normalized potential supply of ecosystem services between 1950 and 2010 in CSP. in part 4.3.2.3.). Similarly, aesthetic and cultural values of the landscape have been improved. In contrast, timber production decreased between 1950 and 2010 because of the large fires that occurred in 1988 and 1990, and past harvests. Because of the opening of the forest by fires and management actions, the 2010 CSP landscape provided a lower level of timber production than in 1950. This planned timber loss, however, provided an income while moving the delivery of ES in the direction proposed by park managers. Overall, changes in ES delivery related to land cover changes affirmed the positive management efforts occurring in the park for the past 60 years.

5.2.3. WCNP: Preservation management of natural resources

As stated in part 4.3.3.1. , the primary goal of the National Park Service in managing Wind Cave National Park is to “conserve the scenery and natural and historic objects and the wildlife therein, and to provide for the enjoyment of the same in such a

[10] Hunting season to control population.

manner and by such means as will leave them unimpaired for the enjoyment of future generations" (Komp 2011). Indeed, in WCNP, wildlife management is a high priority. Wildlife is seen as an ecosystem value rather than an economic value, and they have to be considered in the park management system. WCNP does not have a current General Management Plan in place. However, management plans for prairie dogs, bison, elk, and cave and karst resources exist. The goal is to keep populations the lowest as possible to reduce the stress on grazing land and to ensure responsible management and protection for these park resources (Komp 2011, 11).

The management of the park also considers the natural pre-settlement vegetation of the area, which was more diversified and with more-open stands than it is today. Land cover above the cave has also had a significant impact on the cave's ecosystem and has been highly modified from its natural state during the past century. The Civilian Conservation Corps (CCC) planted hundreds of ponderosa pines above the cave in the mid-1930s and wildfire suppression allowed ponderosa pines to flourish in WCNP. Mature ponderosa pines can evapotranspire up to 1,500 liters of water per day, if it is available, and thus the increase in forest cover reduced the amount of water able to reach the cave, meaning a lower input of carbon and nitrogen from meteoric waters to the cave ecosystem (Komp 2011, 159).

In 1968, there was a radical change in the fire management policy for the National Park Service. It is a three-part policy that acknowledged the legitimate role fire plays in the environment. First, it recognized that prescribed burns are needed to maintain a healthy environment; second, it allows naturally caused fires to burn so long as lives and property are not endangered; and last, it allows for total fire suppression when and where needed (National Park Service 2013). Since the 1970s, the main management action in WCNP has been the use of prescribed fires to (1) reduce accumulated fuel levels, (2) reduce ponderosa pine encroachment on the grasslands, and (3) eliminate non-native plants (namely invasive plant species), while increasing the diversity and health of native plant communities (National Park Service 2005). Because there are no private lands in the park, managers do not have the same conflicts as the BHNF and can use prescribed fires more freely. The management plan, however, also recognizes that the park needs to be aware of the effects fires may have on adjacent landowners (National Park Service 2013). To this aim, WCNP managers do not use prescribed fires next to the park border to be "good neighbors", especially along the west boundary where the BHNF forest has never been cut (old forest that need to burn). As a general rule, in WCNP, managers do not care if fire kills trees, because the wood has no economic value (Burkhart and Schroeder 2012).

Throughout the study period, 82.8 percent of the total land cover change in WCNP was related to prescribed burnings (Figure 63). Since 1980, most of the forest located in the western part of the park has been burned. Consequently, prescribed fires used for land cover management is the primary driver of change in the park. Because of the important dynamic of the ecosystems in WCNP, there was also a small net increase in dense forest area over medium forest area (+1.6 percent of the total WCNP sampled area) that could indicate that the forest has grown faster than mortality or prescribed fire has removed it. The overall land cover change, however, was slight between 1950 and 2010 in WCNP, and the impacts on ES delivery were minor. Cultural services were still the most delivered services in the park because of the significance of heritage and cultural values of the landscape. The important supply of regulation services also demonstrated the large contribution of land cover classes to regulate ecological processes and thus provide benefits to local and national populations. The small change in ES delivery throughout the past 60 years shows the success of park management in protecting natural resources and sustaining the capacity of the WCNP ecosystems to provide ES provision over the long-term.

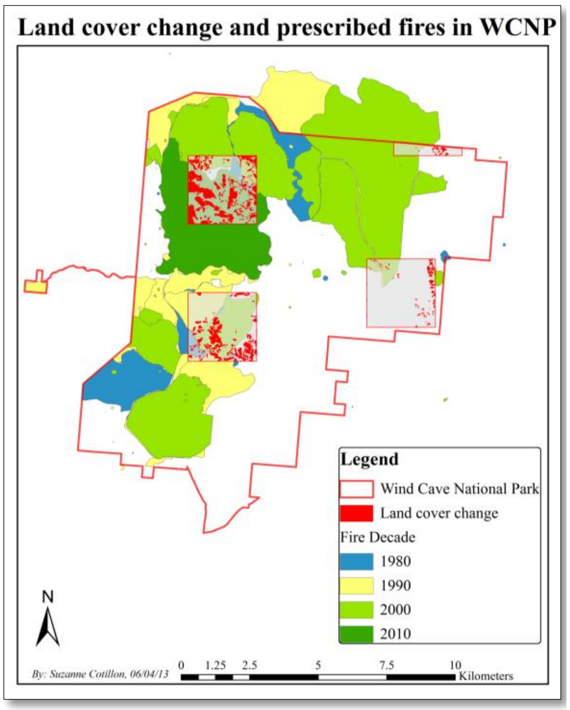


Figure 63. Map of prescribed fires in WNCP and land cover change between 1950 and 2010.

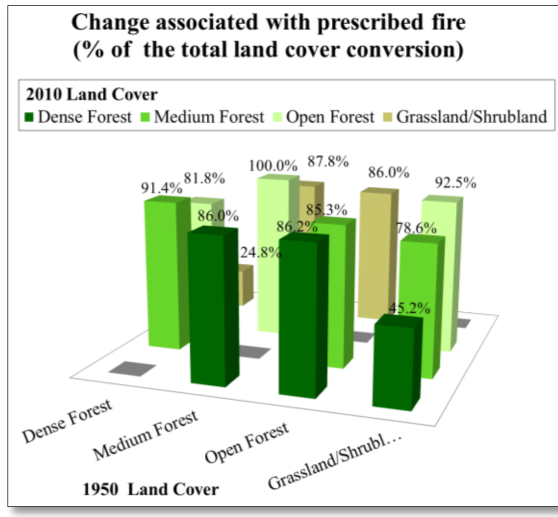


Figure 64. Land cover conversions related to prescribed fires in WCNP.

5.2.4. Private owners

Private land covers 54 percent of the Black Hills ecoregion. The largest blocks in private ownership are at lower elevations in the Foothills regions where grassland/ shrubland is the dominant vegetation and ranches are common (Figure 5 and Figure 65).

There are also concentrations of private land in areas of historical and present-day mining, such as Custer and Lead–Deadwood areas. Many of the high elevation meadows of the Central Core and Limestone Plateau are privately-owned, as they were logical homestead sites with more potential for grazing, cultivation and mineral claims (Hall, Marriott, and Perot 2002) (Figure 65).

Land cover changes on private lands represent 35.2 percent of the total change in the ecoregion. Grassland/shrubland was the dominant land cover (56 percent in 1950 and 49 percent in 2010), followed by dense forest, medium forest, open forest, and cropland. Overall, grassland/shrubland area decreased 6.4 percent from 1950 to 2010 whereas forested land, cropland, and developed land areas increased (Figure 66). During the study period, many land conversions occurred within forest classes to the benefit of the medium forest class, which increased 4.3 percent of the total sampled private land area (Figure 67).

These conversions had several drivers. Fire, which accounted for 2.4 percent of the total land cover change on private land, was only responsible for a minor part of the land conversions from dense, medium, and open forests to grassland (respectively 0.6, 0.4, and 0.2 percent of the total private land sampled area). In the foothills, most of the fires are prairie fires and contribute to maintaining and extending grasslands. Prairie fires, however, have a fast recovery and would not have a long-term impact on ES delivery. The second driver was the landowners' preferences to manage their land. Private owners can choose to maintain grassland/shrubland area for ranching, or promote forestland for commercial and private logging, or for personal enjoyment. Land cover conversions captured for 1950-2010 show that forestland, cropland, and developed land

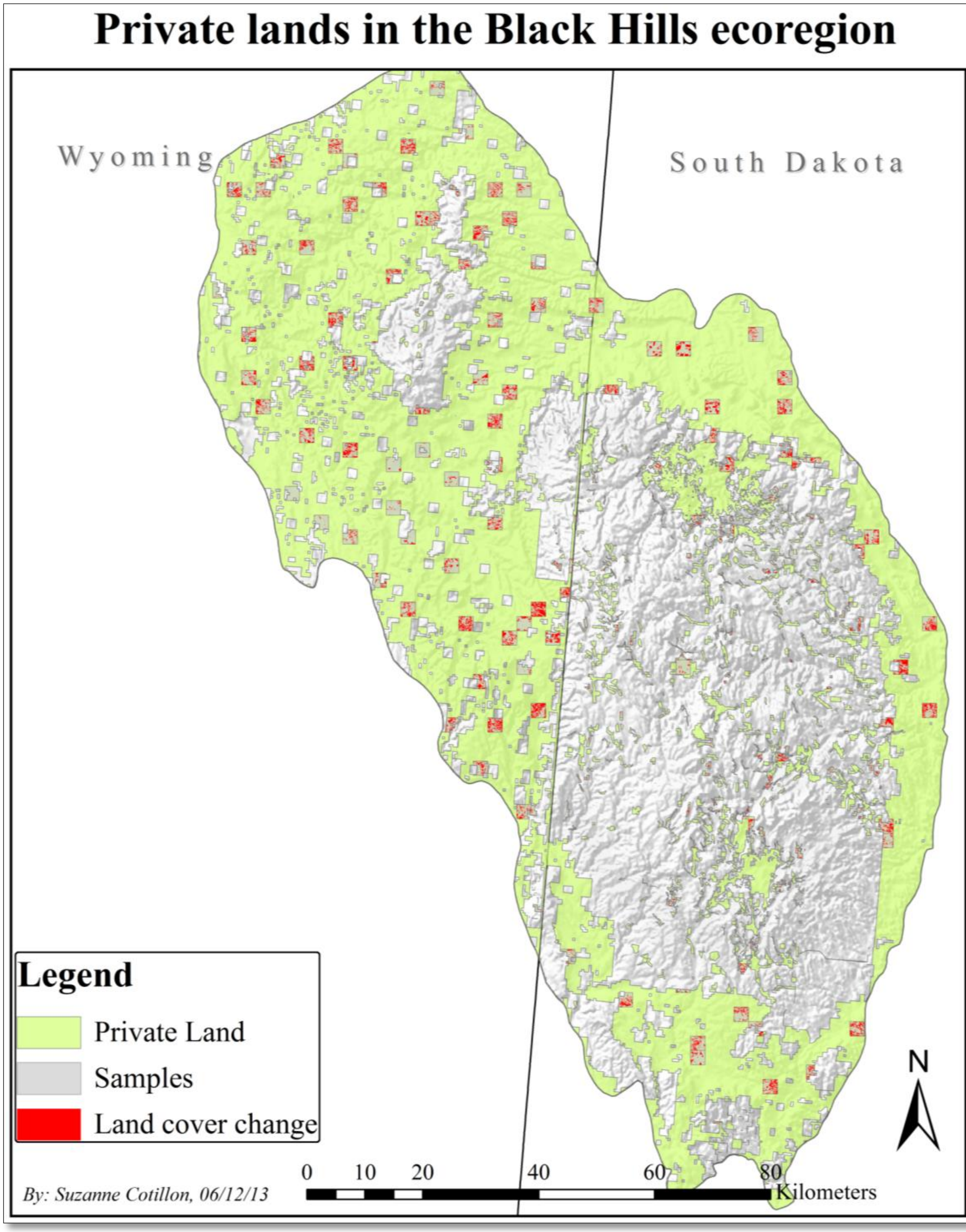
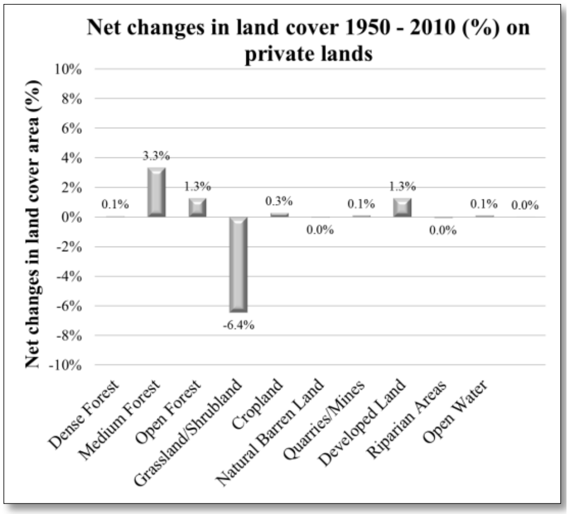


Figure 65. Distribution of private land in the Black Hills ecoregion and associated land cover changes in sampled areas (U.S. Geological Survey 2011).



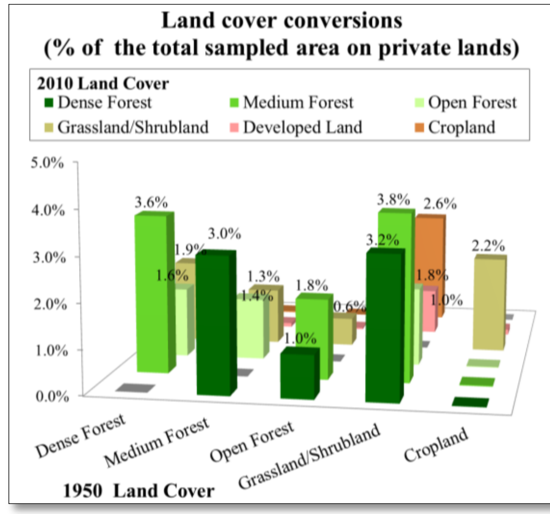


Figure 66. Land cover changes on private lands between 1950 and 2010.

Figure 67. Land cover conversions on private lands between 1950 and 2010.

displaced grassland/shrubland area (Figure 66 and Figure 67). That could indicate that maintaining grassland/shrubland was not the primary goal of private owners. Moreover, in this study, the conversions between cropland and grassland/shrubland classes can be caused by field rotations, and fallows could have been classified as grassland/shrubland because of the similarity of these classes on aerial photographs. Overall, private land management in the Black Hills can explain not only the land cover changes noticed in the Foothills sub-ecoregion (*cf.* Figure 27 in part 4.1.2.), but also most of the minor land cover conversions that occurred in the whole ecoregion (*i.e.*, increase in cropland, increase in developed land, and so forth) (*cf.* Figure 24 in part 4.1.1.).

In the Black Hills of South Dakota, especially in the central hills, the settlement pattern of private lands can be a source of management conflict. By controlling the valley bottoms, private landowners frequently control and therefore limit public access to the public lands above their property. In addition, commodity production activities or intense development on private lands can negatively affect wildlife habitat, wildlife migration, or recreational enjoyment of the adjacent public lands and be a threat for public land management and planning (Loomis 1993). On the other hand, intense commodity production on public lands can seriously detract from the aesthetic qualities on adjoining private lands. This could also be a source of conflict between landowners and public land managers (Loomis 1993).

5.3. Summary of land management and associated drivers of changes

Fires and timber harvest were the main direct drivers of land cover change in the Black Hills ecoregion between 1950 and 2010. While fire was responsible for most of the net decline in forested land, logging modified the structure of the 1950 forest by creating more open stands. In contrast, private owners'decisions explained minor land cover conversions in the ecoregion. Most of the conversions from forests and grassland/shrubland to cropland, developed land, quarries/mines, and open water occurred on private lands, and showed the diversification of uses sought by private owners (Table 11).

The level of impacts of each driver on land cover change, however, varied across the different parts of the ecoregion (Table 12). In the Granitic Core and Limestone Plateau, where the BHNF is the main landowner and manager, timber harvest was the first driver of change, followed by wildfire. Together, they explained 65 percent of the land covers change in the BHNF, accounting for a net loss of dense forest and a net gain of open forest (Table 12). Therefore, changes in ecosystem services delivery were mostly caused by human intervention for land management (*i.e.*, forest management).

In the southern Black Hills, where Custer State Park and Wind Cave National Park are located, there were different patterns because of the various management systems. In CSP, the main driver of change was wildfire for the 1950-2010 period, and thus not a direct consequence of land management. Fires, however, did not explained the totality of land cover changes in CSP (only 56.0 percent) and the Management Plan gave enough information to associate the remaining changes to management actions: timber harvests and prescribed burns. These tools efficiently reduced pine encroachment, increased grassland/shrubland area, and moved the forest toward its initial open structure (Table 12). In CSP, wildfire was the cause of changes in forage, timber production, climate

Table 11. Summary of the land cover conversions in the Black Hills ecoregion directly caused by fire, logging in the BHNF, and management decisions of private owners. To avoid double counting, only land cover conversions outside of fire boundaries have been considered in private lands.

		2010 Land Cover									
1950 Land Cover	**Drivers**	**Dense Forest**	**Medium Forest**	**Open Forest**	**Grassland/Shrubland**	**Cropland**	**Natural Barren Land**	**Quarries/ Mines**	**Developed Land**	**Riparian Areas**	**Open Water**
Dense forest	Fire		5%	5%	38%	-	6%	-	4%	9%	-
	Logging BHNF		50%	71%	22%	-	36%	13%	35%	25%	-
	Private owners		23%	14%	15%	88%	14%	21%	34%	10%	7%
	Total		**79%**	**91%**	**75%**	**88%**	**56%**	**35%**	**73%**	**44%**	**7%**
Medium forest	Fire	3%		16%	41%	-	8%	-	4%	16%	-
	Logging BHNF	24%		49%	8%	-	10%	5%	26%	4%	-
	Private owners	35%		21%	16%	99%	13%	87%	56%	31%	39%
	Total	**62%**		**86%**	**65%**	**99%**	**31%**	**92%**	**86%**	**51%**	**39%**
Open forest	Fire	6%	2%		19%	-	-	-	5%	5%	-
	Logging BHNF	24%	22%		10%	4%	-	46%	18%	-	-
	Private owners	27%	46%		36%	97%	12%	50%	65%	41%	9%
	Total	**57%**	**69%**		**66%**	**101%**	**12%**	**96%**	**88%**	**46%**	**9%**
Grassland/ Shrubland	Fire	22%	4%	5%		-	3%	0%	1%	1%	0%
	Logging BHNF	12%	14%	14%		-	1%	0%	4%	8%	9%
	Private owners	35%	58%	46%		97%	61%	99%	88%	64%	60%
	Total	**68%**	**76%**	**65%**		**97%**	**66%**	**99%**	**93%**	**72%**	**69%**
Cropland	Fire	2.2%	-	-	-		-	-	-	-	-
	Logging BHNF	-	-	-	-		-	-	-	-	-
	Private owners	95.5%	92%	97%	94%		100%	100%	100%	100%	100%
	Total	**98%**	**92%**	**97%**	**94%**		**100%**	**100%**	**100%**	**100%**	**100%**
Natural Barren	Fire	7%	-	7%	6%	-		-	-	-	-
	Logging BHNF	21%	35%	5%	2%	-		-	-	-	-
	Private owners	12%	36%	23%	57%	100%		-	100%	-	-
	Total	**40%**	**71%**	**35%**	**65%**	**100%**		**0%**	**100%**	**0%**	**0%**
Quarries/ Mines	Fire	-	-	-	-	-	-		-	-	-
	Logging BHNF	46%	-	-	-	-	-		-	-	-
	Private owners	53%	100%	100%	84%	-	100%		100%	-	-
	Total	**99%**	**100%**	**100%**	**84%**	**0%**	**100%**		**100%**	**0%**	**0%**

regulation, and water regulation, whereas logging enhanced the level of aesthetic and "sense of place" of the park. In WCNP, the vegetation and land management differed greatly from the other case studies, and consequently the drivers and land cover changes were different. The major management tool used by the National Forest Service in WCNP was prescribed fire, which caused 82.8 percent of the total change in the park. Natural vegetation succession and forest growth explained the remaining land conversions (*i.e.*, from grassland/shrubland to dense and medium forest). Accordingly to the managers' expectations, ecosystem services delivery supplied by WCNP land cover barely changed over the 60-year period.

Each case study had its own management goals, primary driver of land cover changes, different patterns of land cover conversions, and consequently, various changes in ecosystem services delivery (Figure 68). Changes in ecosystem delivery, however, not only depended on land cover changes, but also on the initial state of the environment and some management actions. For instance, enhancing spiritual values of a place by allowing Native American ceremonies on public land improved ecosystem services delivery without changing the land; but it is a direct consequence of decision-making.

Overall, this study shows that the 1950 landscape supplied a higher level of services than in 2010 but in different proportions. In 1950, however, the state of the landscape was "undesirable" because dense forest had taken over the pre-settlement vegetation. Therefore, stakeholders' management for the past 60 years, has brought the 2010 forested Black Hills landscape toward its initial open structure, highlighting the possibility for managers to directly impact and enhance ecosystem services delivery over time.

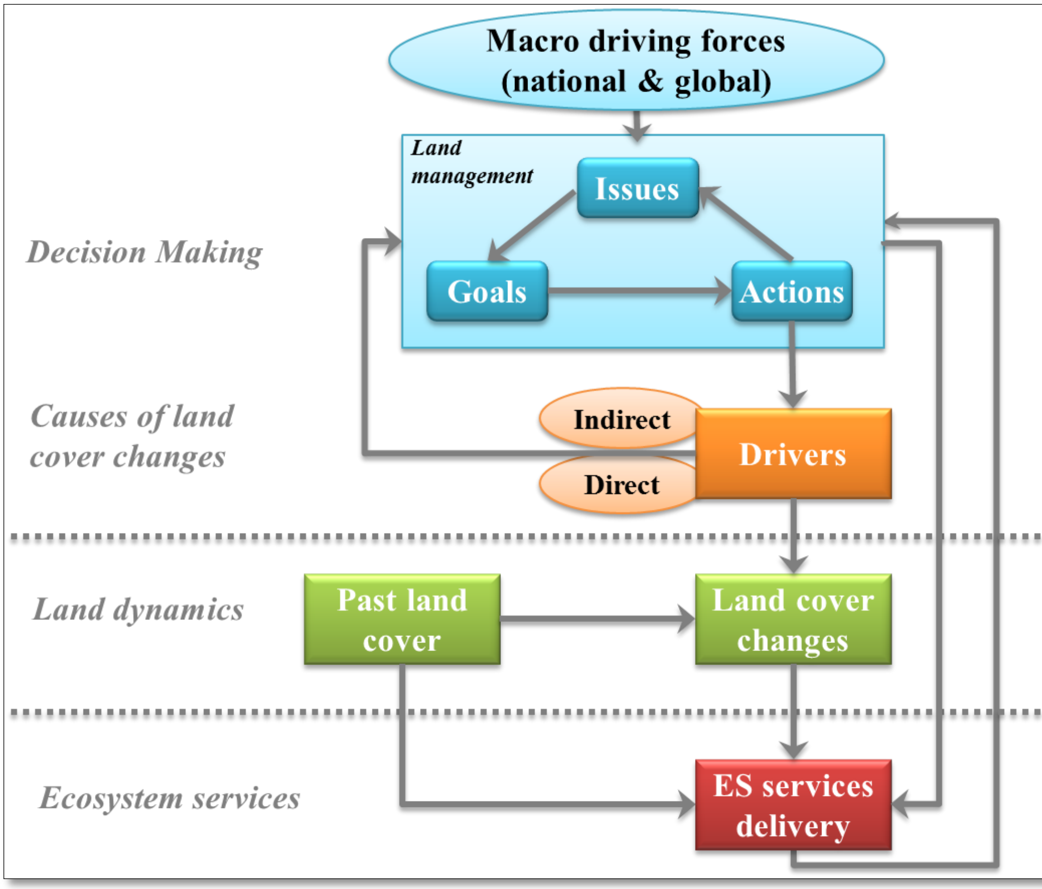


Figure 68. Diagram explaining the links between land management, drivers, land cover changes, and ecosystem services delivery.

Table 12. Summary of land managements, drivers, and associated land cover and ES delivery changes in the ecoregion and in each case study. Drivers are listed by importance in each case study.

CASE STUDY	LAND MANAGEMENT: GOALS	LAND MANAGEMENT: ACTIONS	NET LAND COVER CHANGES 1950-2010: Land cover	(%)	DRIVERS	% OF TOTAL LAND COVER CHANGE	CHANGES IN ECOSYSTEM SERVICES DELIVERY	
Ecoregion			**Land cover**	**(%)**			Crops / Forage	0.32%
			Dense Forest	-6.1%	Private owners	32.8%	Minerals	0.01%
			Medium Forest	2.4%	Timber harvest	29.4%	Timber	-0.54%
			Open Forest	4.8%	Wildfire	12.5%	Freshwater	0.02%
			Grassland/Shrubland	-2.2%	Prescribed fires	Inderterminate	Climate Regulation	-0.18%
			Cropland	0.1%	Recreation/ Tourism	Indirect	Water purification	-0.05%
			Natural Barren Land	0.0%			Erosion Control	-0.05%
			Quarries/Mines	0.1%			Water Regulation	0.07%
			Developed Land	0.7%			Spiritual and Religious	-0.05%
			Riparian Areas	0.0%			Aesthetic	0.21%
			Open Water	0.1%			"Sense of a place" and cultural heritage	0.19%
			Disturbed Land	0.3%			Recreation/Ecotourism	0.06%
BHNF	Improve and maintain wood production, water yield, and forage production, while providing other commercial products, visual quality, diversity of wildlife habitat, recreation opportunities, and a variety of goods and services.	Forest management, harvest (area, location, and method), and prescribed fires. Improve recreation infrastructure (campgrounds, roads, trails, and so forth).	**Land cover**	**(%)**			Crops / Forage	1.02%
			Dense Forest	-12.7%	Timber harvest	51.4%	Minerals	0.00%
			Medium Forest	2.0%	Wildfire	13.6%	Timber	-1.46%
			Open Forest	9.1%	Recreation/ Tourism	Indirect	Freshwater	0.02%
			Grassland/Shrubland	1.1%	Prescribed fires	Inderterminate	Climate Regulation	-0.48%
			Cropland	0.0%			Water purification	-0.04%
			Natural Barren Land	0.0%			Erosion Control	0.02%
			Quarries/Mines	0.0%			Water Regulation	-0.05%
			Developed Land	0.3%			Spiritual and Religious	-0.04%
			Riparian Areas	0.1%			Aesthetic	0.53%
			Open Water	0.1%			"Sense of a place" and cultural heritage	0.46%
			Disturbed Land	0.6%			Recreation/Ecotourism	0.02%
CSP	Reduce pine encroachment with logging and fire on rangeland. Restore the historic fire frequencies through prescribed burns. Enhance productivity and diversity . Simulate the effects of natural disturbances on forested land using forestry tools. Develop and promote the park to its potential as a tourism destination.	Timber harvesting. Prescribed fires. Visitor management, develop, and maintain recreational infrastructures.	**Land cover**	**(%)**			Crops / Forage	1.89%
			Dense Forest	-11.5%	Wildfire	56.0%	Minerals	-
			Medium Forest	-7.9%	Logging	Inderterminate	Timber	-1.32%
			Open Forest	4.4%	Prescribed fires	Inderterminate	Freshwater	0.01%
			Grassland/Shrubland	14.7%	Recreation/ Tourism	Indirect	Climate Regulation	-0.88%
			Cropland	0.2%			Water purification	-0.07%
			Natural Barren Land	0.0%			Erosion Control	-0.07%
			Quarries/Mines	0.1%			Water Regulation	-0.66%
			Developed Land	0.0%			Spiritual and Religious	-0.05%
			Riparian Areas	0.0%			Aesthetic	0.45%
			Open Water	0.0%			"Sense of a place" and cultural heritage	0.76%
			Disturbed Land	0.0%			Recreation/Ecotourism	-0.05%
WCNP	Conserve and improve the scenery and natural and historic objects and the wildlife therein. Reduce accumulated fuel levels. Reduce ponderosa pine encroachment on the grasslands. Eliminate non-native plants while increasing the diversity and health of native plant communities.	Prescribed fires. Visitors management and maintain recreational infrastructures	**Land cover**	**(%)**			Crops / Forage	-
			Dense Forest	1.6%	Prescribed fires	82.8%	Minerals	-
			Medium Forest	-1.4%	Recreation/ Tourism	Indirect	Timber	-
			Open Forest	0.0%			Freshwater	-0.08%
			Grassland/Shrubland	-0.6%			Climate Regulation	0.03%
			Cropland	0.0%			Water purification	0.02%
			Natural Barren Land	-0.1%			Erosion Control	0.02%
			Quarries/Mines	0.0%			Water Regulation	0.03%
			Developed Land	0.2%			Spiritual and Religious	0.00%
			Riparian Areas	0.1%			Aesthetic	-0.07%
			Open Water	0.1%			"Sense of a place" and cultural heritage	0.01%
			Disturbed Land	0.0%			Recreation/Ecotourism	0.03%

MAIN LAND COVER CONVERSIONS 1950-2010

Ecoregion

Land cover in 1950 \ Land cover in 2010	Dense Forest	Medium Forest	Open Forest	Grassland/ Shrubland	Cropland	Developed Land
Dense Forest	-	6.7%	4.7%	4.1%	-	0.2%
Medium Forest	3.9%	-	2.7%	2.5%	-	0.1%
Open Forest	1.6%	1.8%	-	0.8%	-	-
Grassland/Shrubland	4.1%	3.0%	1.7%	-	1.2%	0.5%
Cropland	-	-	-	1.1%	-	0.1%

BHNF

Land cover in 1950 \ Land cover in 2010	Dense Forest	Medium Forest	Open Forest	Grassland/ Shrubland	Cropland	Developed Land
Dense Forest	-	10.4%	8.5%	6.3%	-	0.2%
Medium Forest	5.0%	-	4.2%	3.2%	-	0.1%
Open Forest	2.4%	1.8%	-	0.8%	-	-
Grassland/Shrubland	5.4%	2.2%	1.5%	-	-	0.1%
Cropland	-	-	-	-	-	-

CSP

Land cover in 1950 \ Land cover in 2010	Dense Forest	Medium Forest	Open Forest	Grassland/ Shrubland	Cropland	Developed Land
Dense Forest	-	8.5%	2.2%	7.8%	-	-
Medium Forest	4.0%	-	2.7%	12.9%	-	-
Open Forest	1.6%	1.4%	-	0.7%	-	-
Grassland/Shrubland	1.4%	1.9%	3.3%	-	-	0.1%
Cropland	-	-	-	-	-	-

WCNP

Land cover in 1950 \ Land cover in 2010	Dense Forest	Medium Forest	Open Forest	Grassland/ Shrubland	Cropland	Developed Land
Dense Forest	-	1.6%	0.4%	0.2%	-	-
Medium Forest	2.3%	-	2.0%	1.9%	-	-
Open Forest	0.7%	1.7%	-	1.6%	-	-
Grassland/Shrubland	0.9%	1.6%	1.7%	-	-	0.2%
Cropland	-	-	-	-	-	-

5.4. Limitations and assumptions of the study

5.4.1. Land cover changes analysis

5.4.1.1. The Use of Samples to Classify Land Cover

The sampling strategy used to classify land cover over time has some drawbacks. The samples were used to estimate the various cover type areas for the entire study area. This approach tends to produce more accurate statistics than those generated from an automated classified map, but the major disadvantage is that there is no mapped output. Moreover, there is a small probability that the samples did not capture all the changes or exaggerated others. For instance, if one sample would have been the Lead-Deadwood area in the northern Black Hills, it might have captured more developed land and also more quarries/mines because of the large Homestake Mine in Lead. Furthermore, for this study, the classification results could not be validated, because there was no alternate source to compare with the 1950s aerial photographs.

5.4.1.2. The Use of Aerial Photographs

Working with high resolution aerial photographs allowed the analysis of land cover changes in the Black Hills over a 60-year period at a small scale. These data, however, presented some drawbacks for land cover mapping. Indeed, the quality of the photograph can impact land cover interpretations. For the 2010 imagery, the interpretation was helped by using Google Earth to identify more precisely some features such as quarries or natural barren land versus grassland. This could not be done with the black and white 1950s imagery. For example, the boundaries between grassland/shrubland and cropland were sometimes difficult to establish because the color and the texture of these features were too similar. Similarly, disturbed areas (mountain pine beetle infested areas) could not be mapped in the 1950 imagery because color is needed to detect infestations. Consequently, this land cover class was not considered in the analysis.

5.4.2. Ecosystem Services/Land Cover Indices

5.4.2.1. Scoring system

This study considers the contribution of each land cover class to ES production ranging from 0 (no production of this particular service by this land cover) up to 3 (high production level). This scale can be considered narrow in comparison with other scales, such as the 0 to 5 or the 0 to 100 scales respectively used by Burkhard et al. (2009) and Koschke et al. (2012). Nevertheless, this scale made it easier to distinguish the difference between high, medium, and low productions and thus avoid score assignment uncertainties and mistakes. Like any scoring system it is subjective, depends on the knowledge of the experts, and could be improved by discussions with additional stakeholders/managers assigning scores.

In addition, there are some uncertainties related to the spatial analysis of ES assessment. The most prominent uncertainties in spatial ES assessments are related to the information of land cover/land use data, which in most cases provide the basic spatial units (Hou, Burkhard, and Müller 2013). Spatial interpolations and land cover generalization contain uncertainties with regard to ES supply in reality. ES are supplied spatially heterogeneously, and further generalizations are needed regarding temporal aspects of ecosystem functions and service supply (for instance seasonal variations in natural processes). Several ES, especially cultural services, are difficult to assign to specific spatial units. For example the cultural service “aesthetic value” is, on the one hand, appreciated in a very subjective manner by humans and, on the other hand, related to landscape compositions rather than to single land cover types (Hou, Burkhard, and Müller 2013).

Moreover, to increase the reliability of the scoring system, the study area should be small. Indeed, at a smaller scale the methodology could be improved by defining more land cover classes and analyzing the spatial distribution of ES more precisely (for instance impact of disturbances or landscape fragmentation).

5.4.2.2. Interactions among ecosystem services

Some strong tradeoffs occur between ES and particularly between provisioning and other services (Asner, DeFries, and Houghton 2004; Raudsepp-Hearne, Peterson, and Bennett 2010). There are many bundles of interactions between and among services and each of them may change the potential supply of ES. In the Black Hills National Forest, the production of timber, and especially timber harvest practices, may alter the suitability of the land as well as recreational success such as hunting, but also may have a negative impact on water purification by the ponderosa pine forest (Bowes and Krutilla 1989). On the other hand, the regulation of climate by the forests may have a positive impact on recreation and tourism by providing an attractive climate for human occupation and recreational activities during the tourist season. The developed methodology does not permit a consideration of the various trade-offs between ecosystem services, therefore the consequences of these interactions on the total ES delivery by the landscape can only be assessed qualitatively.

5.4.2.3. Possible impacts of disturbances on ecosystem services

Furthermore, this study does not consider the impacts of disturbances, other than fire, on the potential production of services by land cover classes. For example, some activities such as logging or grazing generated some fragmentation in the landscape that may result in additional changes to the level of ecosystem services production. In the same way, the pressure of mountain pine beetles on the Black Hills forest has been increasing for the past 10 years. In 2012, 136,386 acres were treated, and 625,000 trees were cut to fight the mountain pine beetles epidemic in the Black Hills (USDA 2012a). This epidemic threatens many services produced by the forest, especially timber production, and could at least temporarily decrease the delivery of ES by the Black Hills landscape.

CHAPTER 6. CONCLUSIONS

What story does the Black Hills landscape tell over the past 60 years? This study set out to explore the relationships between land management and ownership, land cover changes and their drivers, and ecosystem services in the Black Hills ecoregion from 1950 to 2010. Using a scoring system to evaluate the capacity of land cover classes to provide ecosystem services, this research demonstrates a changing delivery of ecosystem services following land use/land cover changes.

6.1. Method development

Overall, the developed methodology aims to understand the impacts of land cover changes on ecosystem services while considering all coupled ecosystem services/land cover classes. Most studies that aim to assess or evaluate ecosystem services focus only on a few land cover classes, whereas this framework includes all present land cover types and all relevant ecosystem services. It also allows one to measure and compare the capacity of each land cover unit to produce ecosystem services (*i.e.*, potential production), and the capacity of the whole landscape to deliver each ecosystem service (*i.e.*, potential supply).

This simple methodology presents an alternative approach to ecosystem services assessment that differs from the traditional economic valuation. Unlike the ecosystem function approach and the associated economic valuation of ecosystem services, this method does not require any primary data, except stakeholder cooperation to calibrate the 0-3 scale and fit local conditions and management values, and thus can be applied on any case study. Moreover, since the methodology primarily depends on land cover classification, it works at multiple scales with multiple levels of detail depending upon the need of the research. The scoring system assessment is not new and has been previously used to assess land cover capacities to provide ecosystem services. But in this study, I used a simpler scoring system to make it easy for stakeholders to use, modify, and finally to assess changes in ecosystem services delivery over time. This integrative approach can be useful for communicating possible consequences of land use/land cover change and is needed to take into account ecosystem services in spatial decision-making. Even though the scale of the changes in ecosystem services delivery, based on the 0 to 3 scoring system, was small, the trends of changes in ecosystem services supply in the Black Hills were successfully detected. Further research, however, could define an adequate scoring system as simple as this one, but that could capture ecosystem services changes with a higher amplitude and take into consideration ecosystem services interactions.

6.2. Primary results

6.2.1. Land cover changes and associated drivers

At the ecoregion scale, land ownership appeared to have a significant impact on land cover changes after 1950. While private lands encompassed most of the minor changes and were driven by the personal preferences of and benefits to private owners, public lands such as the Black Hills National Forest, Wind Cave national Park, and Custer State Park, comprised the major land cover changes throughout the study period. The three major net land cover changes occurring in the ecoregion were the loss of dense forest, the gain of medium and open forests, and the decrease in grassland/shrubland area.

The gain of medium and open forests moved the Black Hills landscape closer to what it was like before settlement and before the US Forest Service fire suppression policy that promoted dense forests and fuel buildup.

Land cover changes had several drivers in the Black Hills that were human induced (*i.e.*, management actions) and natural (*i.e.*, wildfires). In the BHNF, 51.4 percent of the total land cover conversions resulted from land management activities. Commercial forest harvest was the major human driver and had major impacts on the delivery of ecosystem services. The methods associated with commercial forest management and cutting changed over time by responding to better science and new non-commercial harvest demands. The BHNF continues to follow multiple use management while optimizing forest production, but with two major changes: (1) it now promotes ecosystem management, and (2) non-commercial uses have increased in importance. As a result, the harvest rate in the BHNF was greatly reduced in the mid-1990s. In CSP, the primary driver of changes was wildfire, and thus was not directly related to managers' actions. The remaining changes in land cover, however, closely followed the management values and goals described in the Resource Management Plan. Moreover, CSP managers strongly promoted tourism and cultural values in the park for the past 60 years, which had an important impact on cultural ecosystem services delivery. Alternatively, in WCNP, land cover changes were driven by prescribed burns, which are a natural process used as a management tool. WCNP managers worked to preserve cultural and natural resources of the park and enhance the current state of the ecosystems. Their moderate management, in comparison with CSP and BHNF, sustained a steady level of ecosystem services delivery for the past 60 years.

6.2.2. The importance of space and time

Following initial land cover distributions, land conversions, and management actions, changes in ecosystem services delivery in the Black Hills varied spatially from north to south by elevation and by location within the Black Hills three sub-ecoregions. Furthermore, the results showed that the whole ecoregion has been undergoing a management transition period. Recent management policies aimed to fix mistakes previously made in natural resources management. From settlement to about 1950, much of the Black Hills were over exploited and over managed. Beginning about 1950, management began to evolve toward an ecosystem approach that also took into account non-economic values. Nature, however, generally does not respond quickly. Even though managers have been working to restore ecosystems, enhance their functionalities, and thus the services they provide, it will likely take many decades to reduce the overall density of the forest and restore it full functionality. Nevertheless, this study provides a baseline for future research on ecosystem services delivery in the Black Hills.

6.3. Conclusion

The developed methodology and the associated results confirmed that land cover change and land management directly influenced the delivery of ecosystem services over time. While the method could be tested in different ecoregions, this study could be strengthened by (1) adding a case study on private lands based on an assessment matrix that would be established by a group of private owners, and (2) quantifying land cover among intermediate time periods to capture more changes at a temporally finer scale (for instance, 1970 and 1990).

Managing for ecosystem services involves understanding the suite of benefits a landscape provides, clarifying relationships between the quality and the quantity of services delivered and the condition of ecosystems that provide them, and recognizing how diverse constituencies value these services. By collaborating, private owners, and federal and state agencies can protect the provision of these services, enhance their quality at the ecoregion scale, and sustain their delivery across the landscape. Taking into account ecosystem services delivery in land planning and management supports sustainable land uses, and should be a priority for the Black Hills managers.

APPENDICES

Appendix A. Statistical Analysis on Sampling Size using Excel

The number of samples in these tables are lower than the total number of sample blocks in each ecoregion because in the NCLD pilot study some of the samples did not capture any land cover change between 2001 and 2006.

Black Hills Core

Land cover change per sample block (hectares)	**T-TEST 1-SAMPLE**				
6.89421	**Test Mean (μ)**	**18.9**			
15.41113	Confidence Level	0.95			
15.12279	Number of samples	17			
6.004636	**Average per block ($\bar{x}$)**	**13.46618**		Test Stdev	p 1-sample Stdev
80.28421	Stdev	18.20073		18.20073	0.906
11.43081	SE Mean	4.414326			
5.115054	T	1.231			
4.069828	TINV	1.745884			
3.687523	**p - One sided**	**0.1180**	**Accept Null Hypothesis because p > 0.05 (Means are the same)**		
3.335909	**p - two sided**	**0.2361**	**Accept Null Hypothesis because p > 0.05 (Means are the same)**		
22.017					
4.225482					
12.7424					
17.01186					
2.891121					
4.225481					
14.4556					

Black Hills Plateau

Land cover change per sample block (hectares)	**T-TEST 1-SAMPLE**				
3.335906	**Test Mean (μ)**	**64.786**			
40.687348	Confidence Level	0.95			
5.337453	Number of samples	40			
173.814358	**Average per block ($\bar{x}$)**	**62.512**		Test Stdev	p 1-sample Stdev
0.366961	Stdev	135.4274		135.4273948	0.940
2.690892	SE Mean	21.41295			
21.527635	T	0.106			
34.009721	TINV	1.684875			
43.229627	**p - One sided**	**0.458**	**Accept Null Hypothesis because p > 0.05 (Means are the same)**		
72.478967	**p - two sided**	**0.916**	**Accept Null Hypothesis because p > 0.05 (Means are the same)**		
3.335908					
61.604688					
24.54819					
5.351259					
181.395895					
5.603817					
17.669109					
396.832296					
47.497929					
10.230118					
50.209229					

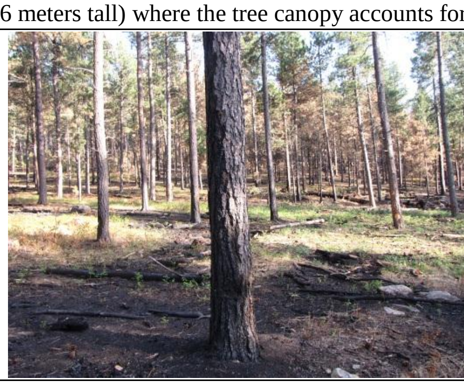
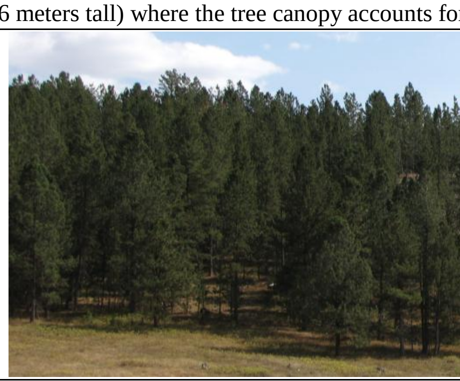
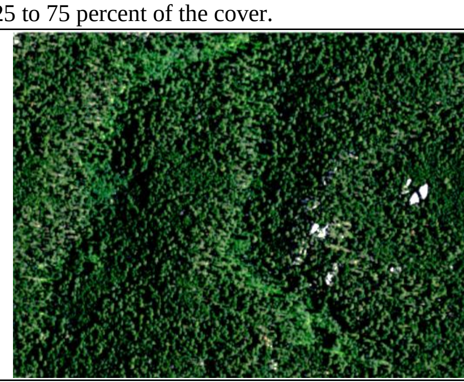
6.004636					
5.648754					
7.016609					
3.335907					
3.617652					
10.452513					
0.733923					
36.748706					
5.559848					
28.301706					
22.868235					
40.475695					
16.509105					
48.54646					
3.921567					
317.747633					
5.307291					
13.121242					
722.837556					

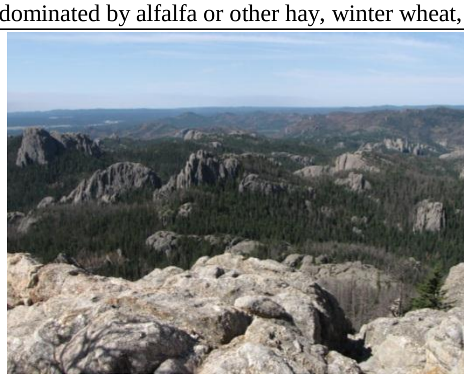
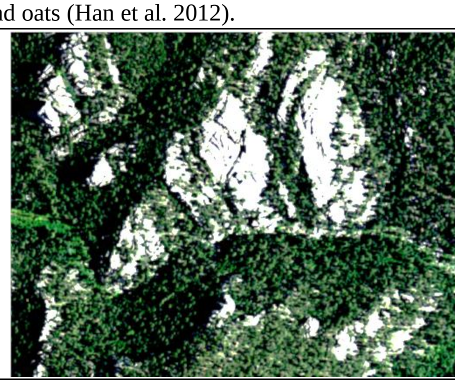
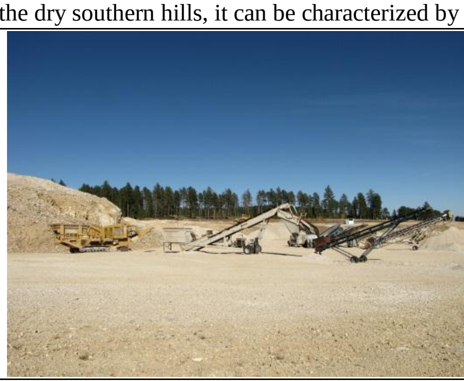
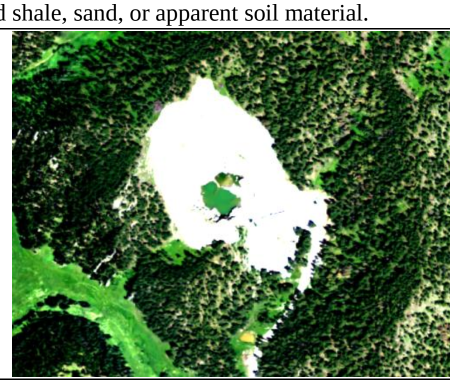
Black Hills Foothills

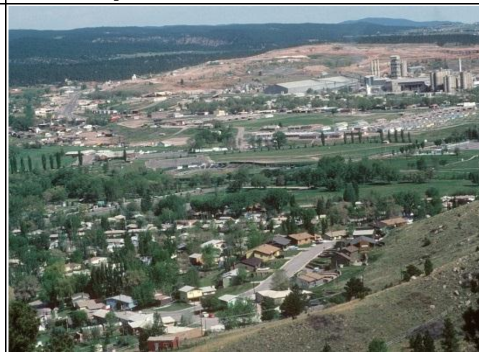
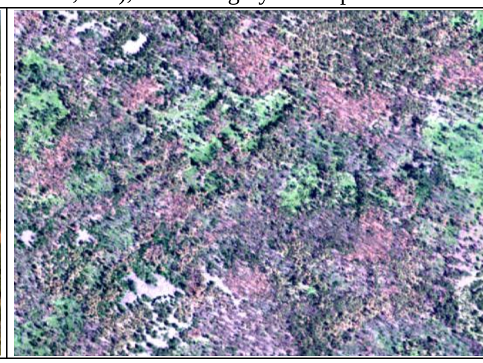
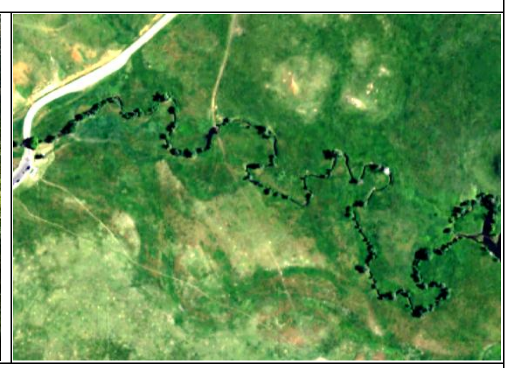
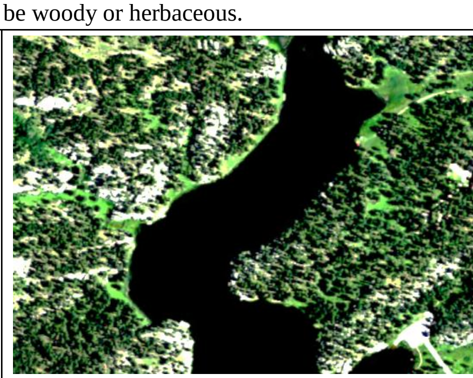
Land cover change per sample block (hectares)	**T-TEST 1-SAMPLE**				
3.335908	**Test Mean (µ)**	**47.907**			
9.785331	Confidence Level	0.95			
135.913	Number of samples	37			
457.1088	**Average per block ($\bar{x}$)**	**43.677**		Test Stdev	p 1-sample Stdev
24.31602	Stdev	96.65217		96.65216839	0.937
0.021984	SE Mean	15.88952			
44.00074	T	0.266			
0.526308	TINV	1.688298			
0.437398	**p - One sided**	**0.3958**	**Accept Null Hypothesis because p > 0.05 (Means are the same)**		
46.65057	**p - two sided**	**0.7916**	**Accept Null Hypothesis because p > 0.05 (Means are the same)**		
1.534589					
4.551565					
0.011084					
16.45715					
29.80078					
11.65242					
5.559844					
13.65089					
33.35909					
4.225482					
83.88902					
40.40726					
93.47598					
389.0902					
1.051643					
26.22903					
28.10817					
10.23012					
15.18214					
14.0108					
3.780695					
5.393112					
23.92611					
8.228573					
0.800665					
20.23627					
9.118152					

Appendix B. Description of Land Cover Classes

The description of land cover class are modified from Fry et al. (2011).

LAND COVER CLASS	GROUND PHOTOGRAPH	AERIAL PHOTOGRAPH (1:2,500)
Open Forest (canopy cover < 25%)		
	Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall) where the tree canopy accounts for 25 percent or less of the cover.	
Medium Forest (25 % < canopy cover < 75%)		
	Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall) where the tree canopy accounts for 25 to 75 percent of the cover.	
Dense Forest (canopy cover > 75%)		
	Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall) where the tree canopy accounts for 75 percent or more of the cover.	

<table>
<tr><td rowspan="2">Grassland/ Shrubland</td><td></td><td></td></tr>
<tr><td colspan="2">Areas characterized by natural or semi-natural herbaceous vegetation or woody vegetation less than 6 meters tall (shrubs, young trees, and trees or shrubs that are small) accounting for 75-100 percent of the cover. These areas are not subject to intensive management, but they are often utilized for grazing.</td></tr>
<tr><td rowspan="2">Cropland</td><td></td><td></td></tr>
<tr><td colspan="2">Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover. In the Black Hills, cropland is dominated by alfalfa or other hay, winter wheat, and oats (Han et al. 2012).</td></tr>
<tr><td rowspan="2">Natural Barren Land</td><td></td><td></td></tr>
<tr><td colspan="2">Perennially barren areas of bedrock, desert pavement, scarps, talus, slides, and other accumulations of earthen material. In the central core, igneous rocks characterize this land cover category, but in the dry southern hills, it can be characterized by red shale, sand, or apparent soil material.</td></tr>
<tr><td>Quarries/ Mines</td><td></td><td></td></tr>
</table>

<table>
<tr><td></td><td colspan="2">Areas of extractive mining activities with significant surface expression. Mostly gravel, sand, or limestone quarries are visible in the Black Hills.</td></tr>
<tr><td rowspan="2">Developed land</td><td></td><td></td></tr>
<tr><td colspan="2">Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g., asphalt, concrete, and buildings). These areas most commonly include single-family housing units and ranches, but also infrastructure (e.g., roads, railroads, etc.), and all highly developed areas.</td></tr>
<tr><td rowspan="2">Disturbed Land</td><td></td><td></td></tr>
<tr><td colspan="2">Areas impacted by natural disturbances such as recent fire (no vegetation recovered) or mountain pine beetle infestation.</td></tr>
<tr><td rowspan="2">Riparian Areas</td><td></td><td></td></tr>
<tr><td colspan="2">Transitional areas between land and streams. Can be woody or herbaceous.</td></tr>
<tr><td rowspan="2">Open Water</td><td></td><td></td></tr>
<tr><td colspan="2">All areas of open water (generally private or public reservoirs).</td></tr>
</table>

Appendix C. RLCM Tool

Rapid Land Cover Mapper (RLCM): An introduction to the USGS's Rapid Land Cover Mapper tool

Cushing, W. M., and Tappan, G. G.
SAIC, contractor to the U.S. Geological Survey (USGS) Center for Earth Resources Observation and Science. Work performed under USGS contract 03CRCN0001
http://edcintl.cr.usgs.gov/ip/rlcm/index.php

What is RLCM?

- The RLCM tool is a vector/raster hybrid approach to land use land cover (LULC) mapping. It lends itself to both multiple resolution and time series mapping of LULC and many other geographic themes.
- Conceptually, it is based on the traditional dot grid method for calculating areas that has long been employed by foresters and other users of aerial photography.

How it works:

- The RLCM tool first generates a digital dot grid for a given study area. Then it overlays that dot grid on an image within ESRI's ArcMap GIS software.
- Using standard photo interpretation techniques, the analyst identifies the discrete LULC class for each dot. The RLCM tool facilitates both the selection and attribution of the dots within a common LULC class.
- It also facilitates the management of multiple time period classifications for the study area.

Once the dot grid matrix is completely classified for a given time period, a raster LULC map can be generated. The same process can be applied to different time periods and the resulting maps can be compared to assess change over time.

RLCM Benefits:

- RLCM enables an analyst to compare images from many different sources.
- Using local knowledge, photo interpreters are able to integrate many different landscape characteristics into an interpretation.
- The method facilitates rapid mapping for a large area.
- RLCM is effective for time series mapping because the interpreter can determine whether real LULC change has occurred at each dot over time.
- It allows the use of nested dot grids for the creation of multiple resolution LULC datasets.
- It is easy to use.

Using RLCM, An Overview:

- Planning
  - Determine spatial extent and resolution of study area.
  - Identify the required time periods.
  - Determine the classification system to use.
- Preparation
  - Collect and prepare imagery to be used in RLCM.
  - Set up RLCM software.
  - Build RLCM image library.
  - Define time periods within RLCM.
  - Import LCCS classification, if required.
  - Build study area with RLCM.
- Product development
  - Classify study area for all time periods.
  - Export RLCM time period data for analysis.
  - Product development workflow.

Appendix D. Justification of the level of production of ecosystem services by each land cover class

The choices of level of production for each coupled land cover/ecosystem services are detailed for the ecoregion. Then matrices are presented for each case study and each modified value is highlighted and justified.

1) Assessment matrix of potential production of ecosystem services by each of land cover unit in the Black Hills ecoregion

	PROVISIONING SERVICES				REGULATION SERVICES				CULTURAL SERVICES			
	Crops /Forage	Minerals	Timber	Fresh-water	Climate Regulation	Water purification	Erosion Control	Water Regulation	Spiritual/ Religious	Aesthetic	"Sense of a place"/ cultural heritage	Recreational
Dense Forest	0	0	3	0	3	3	3	2	3	2	2	3
Medium Forest	1	0	2	0	3	3	3	2	3	3	2	3
Open Forest	2	0	0	0	2	3	3	2	3	3	3	3
Grassland/ Shrubland	3	0	0	0	2	3	3	1	3	3	3	3
Cropland	3	0	0	0	1	0	1	1	0	0	0	0
Natural Barren Land	0	0	0	0	0	0	0	0	3	3	2	3
Quarries/Mines	0	3	0	0	0	0	0	0	0	0	0	0
Developed Land	0	0	0	0	0	0	0	0	0	0	3	3
Riparian Areas	0	0	0	3	3	3	3	3	0	3	0	1
Open Water	0	0	0	3	0	0	0	3	0	3	1	3
Disturbed Land	2	0	0	0	0	0	0	0	0	0	0	0

The justification for each index is given in the next table.

<table>
<tr><th></th><th colspan="4">PROVISIONING SERVICES</th><th colspan="4">REGULATING SERVICES</th><th colspan="4">CULTURAL SERVICES</th></tr>
<tr><th></th><th>Crops /Forage</th><th>Minerals</th><th>Timber</th><th>Fresh-water</th><th>Climate Regulation</th><th>Water purification</th><th>Erosion Control</th><th>Water Regulation</th><th>Spiritual/ Religious</th><th>Aesthetic</th><th>"Sense of a place"/ cultural heritage</th><th>Recreation/ Ecotourism</th></tr>
<tr><td>Dense Forest</td><td>Production of forage is negligible because of the density of the canopy.</td><td>-</td><td>Most productive system for timber</td><td rowspan="3">-</td><td rowspan="2">High carbon sequestration by dense stands of pines. Forests help to reduce the extremes of temperature and conserve precipitation</td><td rowspan="4">Vegetation contributes greatly to water filtration by roots system</td><td rowspan="3">Trees' intricate root system provides protection of the soil, which stabilizes natural landscapes, thus reducing landslides (Matlock and Morgan 2011, 254)</td><td rowspan="3">Forest canopy, litter floor, and deep root systems reduce run-off by intercepting rainfalls and helping water infiltration (Chang 2003, 193)</td><td rowspan="3">The forested landscape of the Black Hills (Paha Sapa) contributes to Indian "sacred landscape."</td><td>People prefer forested environments (Kaplan and Kaplan 1989, 35)</td><td rowspan="2">The Black Hills is rich in human history and its forested landscape is a part of the identity of this place.</td><td rowspan="4">Forests and grasslands provide places to hunt, fish, hike, camp, and bird watch (Matlock and Morgan 2011, 254). The accessibility of the forest in the Black Hills adds value to this service.</td></tr>
<tr><td>Medium Forest</td><td>Small production of forage for cattle.</td><td>-</td><td>Produces less timber than dense forest because the stands are most opened.</td><td rowspan="3">People prefer environments that are relatively open and generally forested (Kaplan and Kaplan 1989, 35 and 48)</td></tr>
<tr><td>Open Forest</td><td>Important production of forage (understory) for cattle.</td><td>-</td><td>In the short term, no exploitation</td><td>Open vegetation with an high understory that stored carbon above and belowground</td><td rowspan="2">Open forest and prairies are the natural vegetation of the Black Hills recorded in expedition journals or diaries, and thus have a higher heritage value.</td></tr>
<tr><td>Grassland/ Shrubland</td><td>Provides grasses and forbs for livestock (range) (Matlock and Morgan 2011, 255)</td><td>-</td><td>-</td><td>-</td><td>Low vegetation but important roots biomass (storage of carbon belowground) (Daily 1997, 248). Moreover, vegetation cover on grassland/shrubland help regulate surface temperature (Hassan et al. 2005, 631)</td><td>Dense root system help prevent soil erosion (Daily 1997, 247)</td><td rowspan="2">Vegetation cover modulates water by intercepting rainfall and promoting water infiltration (Hassan et al. 2005, 630) but at a lower level than forest (Chang 2003, 193).</td><td>Grassland associated with bison (tatanka) is also a main component of the sacred landscape.</td></tr>
<tr><td>Cropland</td><td>Food production for humans or livestock.</td><td>-</td><td>-</td><td>-</td><td>Contributes to the storage of carbon but for short-term.</td><td>-</td><td>Perennial crops such as hay or alfalfa contribute to stabilizing the soil and decreasing erosion.</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Natural Barren Land</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>The Needles, and granitic features such as Harney Peak, are among sacred sites.</td><td>Granitic intrusions of the Black Hills are a major part of the scenic value of the ecoregion.</td><td>The Needles, Mount Rushmore, and all granitic barren lands increase the identity of the Black Hills.</td><td>The granitic parts of the Black Hills are one of the main attractions for recreation.</td></tr>
<tr><td>Quarries/ Mines</td><td>-</td><td>Mostly gravels and sand extraction. Mines are exploited for gold, mica, and silver.</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Developed Land</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>Many lodges, roads, bridges, and other developed structures were built by the CCC and have an historical importance.</td><td>Camping, lodging, non-motorized roads, and motorized roads are essential to recreation and tourism.</td></tr>
<tr><td>Riparian Areas</td><td>-</td><td>-</td><td>-</td><td>Important storage sites, accumulating water during wet periods and helping maintain base flow during dry period (Hassan et al. 2005, 555).</td><td>Riparian vegetation sequesters carbon from the atmosphere and traps carbon-rich sediments from watershed sources (Hassan et al. 2005, 558; Matlock and Morgan 2011, 257)</td><td>Riparian vegetation traps sediments, nutrients, and pollutants by filtering the running water (Hassan et al. 2005, 556).</td><td>Deep roots network contributes to soil stabilization (Matlock and Morgan 2011, 257).</td><td rowspan="2">Attenuates floods by retaining water or storing it in the soil and recharging groundwater (Hassan et al. 2005, 555).</td><td>-</td><td rowspan="2">Water is a high preference in a natural landscape (Kaplan and Kaplan 1989, 9).</td><td>-</td><td>Riparian areas provide recreational services by bringing in tourists for bird watching, hunting, and fishing (Matlock and Morgan 2011, 254)</td></tr>
<tr><td>Open Water</td><td>-</td><td>-</td><td>-</td><td>High storage of water in reservoirs.</td><td>-</td><td>-</td><td>-</td><td>-</td><td>Reservoirs are a part of the CCC interventions.</td><td>Provide many recreational opportunities such as boating, fishing, canoeing, and so forth.</td></tr>
</table>

2) Assessment matrix of potential production of ecosystem services by each land cover unit in the Black Hills National Forest

	PROVISIONING SERVICES				REGULATION SERVICES				CULTURAL SERVICES			
	Crops /Forage	Minerals	Timber	Fresh-water	Climate Regulation	Water purification	Erosion Control	Water Regulation	Spiritual/ Religious	Aesthetic	"Sense of a place"/ cultural heritage	Recreational
Dense Forest	0	0	3	0	3	3	**2**	2	3	2	2	3
Medium Forest	1	0	2	0	3	3	**2**	2	3	3	2	3
Open Forest	2	0	0	0	2	3	**2**	2	3	3	3	3
Grassland/ Shrubland	3	0	0	0	2	3	3	1	3	3	3	3
Cropland	***No cropland in the Black Hills National Forest***											
Natural Barren Land	0	0	0	0	0	0	0	0	3	3	2	3
Quarries/Mines	0	3	0	0	0	0	0	0	0	0	0	0
Developed Land	0	0	0	0	0	0	0	0	0	0	3	3
Riparian Areas	0	0	0	3	3	3	3	3	0	3	0	1
Open Water	0	0	0	3	0	0	0	3	0	3	1	3

The Black Hills National Forest represents 36.1 percent of the whole ecoregion, thus the ecoregion indices are mostly based on the BHNF indices and few indices changed in this case study. The important human intervention in the BHNF associated with mechanical logging and roads construction decreases the level of erosion control in forested area.

3) <u>Assessment matrix of potential production of ecosystem services by each land cover unit in Custer State Park</u>

	PROVISIONING SERVICES				**REGULATION SERVICES**				**CULTURAL SERVICES**			
	Forage	**Minerals**	**Timber**	**Fresh-water**	**Climate Regulation**	**Water purification**	**Erosion Control**	**Water Regulation**	**Spiritual/ Religious**	**Aesthetic**	**"Sense of a place"/ cultural heritage**	**Recreational**
Dense Forest	0	***No minerals extraction***	**2**	0	3	3	3	2	3	2	2	3
Medium Forest	1		**1**	0	3	3	3	2	3	3	2	3
Open Forest	2		0	0	2	3	3	2	3	3	3	3
Grassland/ Shrubland	3		0	0	2	3	3	1	3	3	3	3
Cropland			***No cropland in Custer State Park***									
Natural Barren Land	0		0	0	0	0	0	0	3	3	2	3
Quarries/Mines	0		0	0	0	0	0	0	0	0	0	0
Developed Land	0		0	0	0	0	0	0	0	0	3	3
Riparian Areas	0		0	3	3	3	3	3	0	3	0	1
Open Water	0		0	3	0	0	0	3	0	3	1	3

There is no cropland and no mineral extraction in Custer State Park. However, forage production is maintained as a provisioning service in this case study because the park management includes commercialization of bison for human consumption. Forest management is less intense in Custer State Park than in the National Forest and results in a lower level of timber production by the park's ecosystems.

4) <u>Assessment matrix of potential production of ecosystem services by each land cover unit in Wind Cave National Park</u>

	PROVISIONING SERVICES				REGULATION SERVICES				CULTURAL SERVICES			
	Forage	**Minerals**	**Timber**	**Fresh-water**	**Climate Regulation**	**Water purification**	**Erosion Control**	**Water Regulation**	**Spiritual/ Religious**	**Aesthetic**	**"Sense of a place"/ cultural heritage**	**Recreational**
Dense Forest	***No livestock***	***No mineral extraction***	***No commercial logging***	0	3	3	3	2	3	2	2	3
Medium Forest				0	3	3	3	2	3	3	2	3
Open Forest				0	2	3	3	2	3	3	3	3
Grassland/ Shrubland				0	2	3	3	1	3	3	3	3
Cropland				***No cropland in Wind Cave National Park***								
Natural Barren Land				0	0	0	0	0	**0**	**1**	**0**	**0**
Quarries/Mines				***No quarries in Wind Cave National Park***								
Developed Land				0	0	0	0	0	0	0	3	3
Riparian Areas				3	3	3	3	3	0	3	0	1
Open Water				***No reservoirs or ponds in Wind Cave National Park***								

In Wind Cave National Park, there is no commercial resources exploitation and thus forage, timber, and mineral productions are not considered in this case study. Moreover, “natural barren land” class in the park represents dry barren soil unlike in the central granitic part of the Black Hills.

REFERENCES

Asner, Gregory P., Ruth S. DeFries, and Richard A. Houghton. 2004. Typological Responses of Ecosystems to Land Use Change. *Geophysical Monograph* (153):337-344.

Ayanu, Y. Z., C. Conrad, T. Nauss, M. Wegmann, and T. Koellner. 2012. Quantifying and mapping ecosystem services supplies and demands: a review of remote sensing applications. *Environmental science & technology* 46 (16):8529-41.

Bailey, Robert G., and Lev Ropes. 1998. *Ecoregions: the ecosystem geography of the oceans and continents: with 106 illustrations, with 55 in color*. New York: Springer.

———. 2002. *Ecoregion-based design for sustainability*. New York: Springer.

Ball, John. 2005. Forest Health Conditions and Forest Management Practices on the Black Hills National Forest. Hill City, SD: South Dakota State University.

Ball, John J., and Peter R. Schaefer. 2000. History - Case No 1: One Hundred Years of Forest Management - The first regulated sale of timber from a forest reserve, in the Black Hills National Forest, shows how effective management can sustain multiple forest resources. *Journal of forestry.* 98 (1):4.

Bennett, Elena M., Garry D. Peterson, and Line J. Gordon. 2009. Understanding relationships among multiple ecosystem services. *Ecology Letters* 12 (12):1394-1404.

Black Hills National Forest. *Streams*. Black Hills National Forest 2000 [cited. Available from http://www.fs.usda.gov/detail/blackhills/landmanagement/gis/?cid=stelprdb5112504.

———. 2011. Black Hills National Forest Historic Timber Sale Units. Custer, SD.

Bowes, Michael D., and John V. Krutilla. 1989. *Multiple-use management : the economics of public forestlands*. Washington, D.C.: Resources for the Future.

Boyte, Stephen Perry. 2009. Modeling fire disturbance and forest structure change in the Black Hills, Master of Sciences Thesis in Geography., South Dakota State University, Brookings, SD.

Brundige, Gary. 2012. Personal Communication. Custer State Park. Custer, SD, September 25.

Burkhard, Benjamin, Franziska Kroll, Felix Müller, and Wilhelm Windhorst. 2009. Landscapes' Capacities to Provide Ecosystem Services – a Concept for Land-Cover Based Assessments. *Landscape Online* (15):22.

Burkhard, Benjamin, Franziska Kroll, Stoyan Nedkov, and Felix Müller. 2012. Mapping ecosystem service supply, demand and budgets. *Ecological Indicators* 21:17-29.

Burkhart, Beth, and Greg Schroeder. 2012. Personal Communication. Wind Cave National Park. Hot Springs, SD, November, 5.

Busch, Malte, Alessandra La Notte, Valérie Laporte, and Markus Erhard. 2012. Potentials of quantitative and qualitative approaches to assessing ecosystem services. *Ecological Indicators* 21:89-103.

Buttrick, P. L. 1914. The Probable Origin of the Forests of the Black Hills of South Dakota. *Forestry Quarterly* 4:223-227.

Campbell, Elliott T., and Mark T. Brown. 2012. Environmental accounting of natural capital and ecosystem services for the US National Forest System. *Environment, Development and Sustainability* 14 (5):691-724.

Carpenter, S. R., H. A. Mooney, J. Agard, D. Capistrano, R. S. Defries, S. Diaz, T. Dietz, A. K. Duraiappah, A. Oteng-Yeboah, H. M. Pereira, C. Perrings, W. V. Reid, J. Sarukhan, R. J. Scholes, and A. Whyte. 2009. Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proceedings of the National Academy of Sciences of the United States of America* 106 (5):1305-1312.

Carter, J. M., and D. G. Driscoll. 2006. Estimating recharge using relations between precipitation and yield in a mountainous area with large variability in precipitation. *Journal of Hydrology* 316 (1-4):71-83.

Chang, Mingteh. 2003. *Forest hydrology : an introduction to water and forests*. Boca Raton, FL: CRC Press.

Clark, William C., and Jessica T. Mathews. 1990. Editorial Introduction. In *The Earth as transformed by human action: global change and regional changes in the biosphere over the past 300 years*, eds. B. L. Turner II, W. C. Clark, R. W. Kates, J. F. Richards, J. T. Mathews and W. B. Meyer. Cambridge University Press, with Clark University.

Cliff, E.P. 1970. Report of the Chief of the Forest Service. US Departement of Agriculture. Washington, D.C.

Costanza, Robert. 2008. Ecosystem services: Multiple classification systems are needed. *Biological Conservation* 141 (3):350-352.

Costanza, Robert, Ralph d'Arge, Rudolf de Groot, Stephen Farber, Monica Grasso, Bruce Hannon, Karin Limburg, Shahid Naeem, Robert V. O'Neill, Jose Paruelo, Robert G. Raskin, Paul Sutton, and Marjan van den Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387 (6630):253-260.

Daily, Gretchen C. 1997. *Nature's services : societal dependence on natural ecosystems*. Washington, DC: Island Press.

Daily, Gretchen C., and P. A. Matson. 2008. Ecosystem services: from theory to implementation. *Proceedings of the National Academy of Sciences of the United States of America* 105 (28):9455-6.

de Groot, Rudolf S., R. Alkemade, L. Braat, L. Hein, and L. Willemen. 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* 7 (3):260-272.

de Groot, Rudolf S., Matthew A. Wilson, and Roelof M. J. Boumans. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological economics : the journal of the International Society for Ecological Economics.* 41 (3):393.

DeBlander, Larry T. 2002. Forest Resources of the Black Hills National Forest. USDA. Forest Service. Rocky Mountain Research Station. Ogden, UT.

DeFries, Ruth S., Gregory P. Asner, and Richard A. Houghton. 2004. *Ecosystems and land use change*. Washington, DC: American Geophysical Union.

DeFries, Ruth S., and Lahouari Bounoua. 2004. Consequences of land use change for ecosystem services: A future unlike the past. *GeoJournal* 61 (4):345-351.

DeFries, Ruth S., Jonathan A. Foley, and Gregory P. Asner. 2004. Land-Use Choices: Balancing Human Needs and Ecosystem Function. *Frontiers in Ecology and the Environment* 2 (5):249-257.

DeWitt, Ed. 1989. Geologic map of the Black Hills area, South Dakota and Wyoming. Reston, VA; Denver, CO: U.S. Geological Survey.

Diaz, R. J., and R. Rosenberg. 2008. Spreading Dead Zones and Consequences for Marine Ecosystems. *Science Science* 321 (5891):926-929.

Driscoll, Daniel G., Janet M. Carterm, Joyce E. Williamson, and Larry D. Putnam. 2002. Hydrology of the Black Hills Area, South Dakota. U.S. Department of the Interior. U.S. Geological Survey. Rapid City, SD.

Egoh, Benis, Belinda Reyers, Mathieu Rouget, David M. Richardson, David C. Le Maitre, and Albert S. van Jaarsveld. 2008. Mapping ecosystem services for planning and management. *Agriculture, Ecosystems & Environment* 127 (1–2):135-140.

Eigenbrod, F., P. R. Armsworth, K. J. Gaston, B. J. Anderson, C. D. Thomas, A. Heinemeyer, S. Gillings, and D. B. Roy. 2010. The impact of proxy-based methods on mapping the distribution of ecosystem services. *Journal of Applied Ecology* 47 (2):377-385.

Ericksen, Polly de Leeuw Jan Said Mohammed Silvestri Silvia Zaibet Lokman. 2012. Mapping ecosystem services in the Ewaso Ng'iro catchment. *International Journal of Biodiversity Science, Ecosystem Services & Management International Journal of Biodiversity Science, Ecosystem Services & Management* 8 (1-2):122-134.

Farber, Stephen, Robert Costanza, Daniel L. Childers, Jon Erickson, Katherine Gross, Morgan Grove, Charles S. Hopkinson, James Kahn, Stephanie Pincetl, Austin Troy, Paige Warren, and Matthew Wilson. 2006. Linking Ecology and Economics for Ecosystem Management. *BioScience* 56 (2):121-133.

Fedkiw, John. 1998. *Managing multiple uses on National Forests, 1905-1995 : a 90-year learning experience and it isn't finished yet*. [Washington, D.C.]: USDA Forest Service.

Fiacco, Brian. *National Forest Harvest. The Timberland Blog - Examining the changes in timberland ownership and what those changes might mean.*, 01/21/2010 2010 [cited 06/11/2013. Available from http://thetimberlandblog.blogspot.com/2010/01/national-forest-harvest.html.

Foley, J. A., R. Defries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Patz, I. C. Prentice, N. Ramankutty, and P. K. Snyder. 2005. Global consequences of land use. *Science* 309 (5734):570-4.

Fontaine, T. A., J. F. Klassen, T. S. Cruickshank, and R. H. Hotchkiss. 2001. Hydrological response to climate change in the Black Hills of South Dakota, USA. *Hydrological Sciences Journal* 46 (1):27-40.

Forstall, Richard L. 1995. Population of Counties by Decennial Census: 1900 to 1990. South Dakota. US Bureau of the Census. Washington, DC. http://www.census.gov/population/cencounts/sd190090.txt

Froiland, Sven G. 1990. Natural History of the Black-Hills and Badlands. *Great Plains Quarterly* 12 (3):220.

Fry, J. A., J. A. Dewitz, C. G. Homer, G. Xian, S. Jin, L. Yang, C. A. Barnes, N. D. Herold, and J. D. Wickham. 2011. Completion of the 2006 national land cover database for the conterminous united states. *Photogrammetric Engineering and Remote Sensing* 77 (9):858-864.

Gallant, Alisa L., Thomas R. Loveland, Terry L. Sohl, and Darrell E. Napton. 2004. Using an Ecoregion Framework to Analyze Land-Cover and Land-Use Dynamics. *Environmental Management* 34 (Supplement):89.

Geores, Martha. 1996. *Common ground : the struggle for ownership of the Black Hills National Forest*. Lanham, Md.: Rowman & Littlefield Publishers.

Gomez-Baggethun, E., and M. Ruiz-Perez. 2011. Economic valuation and the commodification of ecosystem services. *Prog. Phys. Geogr. Progress in Physical Geography* 35 (5):613-628.

Gómez-Baggethun, Erik, Rudolf de Groot, Pedro L. Lomas, and Carlos Montes. 2010. The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. *Ecological Economics* 69 (6):1209-1218.

Gordon, L. J., G. D. Peterson, and E. M. Bennett. 2008. Agricultural modifications of hydrological flows create ecological surprises. *Trends Ecol. Evol. Trends in Ecology and Evolution* 23 (4):211-219.

Hall, Jennifer S., Hollis J. Marriott, and Jennifer K. Perot. 2002. Ecoregional Conservation in the Black Hills. The Nature Conservancy. Minneapolis, MN.

Han, Weiguo, Zhengwei Yang, Liping Di, and Richard Mueller. 2012. CropScape: A Web service based application for exploring and disseminating US conterminous geospatial cropland data products for decision support. *Computers and Electronics in Agriculture* 84 (0):111-123.

Hassan, Rashid M., Robert Scholes, Neville Ash, Condition Millennium Ecosystem Assessment, and Group Trends Working. 2005. *Ecosystems and human well-being : current state and trends, volume 1 : findings of the Condition and Trends Working Group of the Millennium Ecosystem Assessment*. Washington, DC: Island Press.

Hermann, Anna, Sabine Schleifer, and Thomas Wrbka. 2011. The concept of ecosystem services regarding landscape research: A review. *Living Reviews in Landscape Research* 5 (1):1-37.

Hodgins, Robert A., and James Sprague. 1969. Custer State Park, Commemorative Issue. *South Dakota Conservation Digest*.

Hou, Y., B. Burkhard, and F. Müller. 2013. Uncertainties in landscape analysis and ecosystem service assessment. *Journal of Environmental Management Journal of Environmental Management*.

Intergovernmental Panel on Climate Change. 2007. *Climate change 2007 : the physical science basis : contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge; New York: Cambridge University Press.

Julin, Suzanne. 2009. *A marvelous hundred square miles : Black Hills tourism, 1880-1941*. Pierre: South Dakota State Historical Society Press.

Kandziora, Marion , Benjamin Burkhard, and Felix Müller. 2013. Interactions of ecosystem properties, ecosystem integrity and ecosystem service indicatorsA theoretical matrix exercise. *ECOIND Ecological Indicators* 28:54-78.

Kaplan, Rachel , and Stephen Kaplan. 1989. *The experience of nature : a psychological perspective*. Cambridge; New York: Cambridge University Press.

Komp, M. R., K. J. Stark, A. J. Nadeau, S. Amberg, E. Iverson, L. Danzinger, L. Danielson, and B. Drazkowski. 2011. Wind Cave National Park: Natural resource condition assessment. Natural Resource Report NPS/WICA/NRR—2011/478. National Park Service. Fort Collins, Colorado.

Koschke, Lars, Christine Fürst, Susanne Frank, and Franz Makeschin. 2012. A multi-criteria approach for an integrated land-cover-based assessment of ecosystem services provision to support landscape planning. *Ecological Indicators Ecological Indicators* 21:54-66.

Lant, Christopher L., J. B. Ruhl, and Steven E. Kraft. 2008. The Tragedy of Ecosystem Services. *American Institute of Biological Sciences BioScience* 58 (10):969-974.

Larson, Gary, and James R. Johnson. 1999. *Plants of the Black Hills and Bear Lodge Mountains*. Brookings, S.D.: South Dakota State University.

Lautenbach, Sven, Carolin Kugel, Angela Lausch, and Ralf Seppelt. 2011. Analysis of historic changes in regional ecosystem service provisioning using land use data. *Ecological Indicators* 11 (2):676-687.

Lindenmayer, David, and Joern Fischer. 2006. *Habitat fragmentation and landscape change : an ecological and conservation synthesis*. Washington: Island Press.

Logsdon, Rebecca A. 2011. Development of a quantification method for ecosystem services. 1501870, Purdue University, United States -- Indiana.

Loomis, John B. 1993. *Integrated public lands management : principles and applications to national forests, parks, wildlife refuges, and BLM lands*. New York: Columbia University Press.

Marschner, F. J. 1959. *Land use and its pattern in the United States*. Washington, D.C.: U.S. Dept. of Agriculture.

Matlock, Marty D., and Robert A. Morgan. 2011. *Ecological engineering design : restoring and conserving ecosystem services*. Hoboken, NJ: Wiley.

Metzger, M. J., M. D. A. Rounsevell, L. Acosta-Michlik, R. Leemans, and D. Schröter. 2006. The vulnerability of ecosystem services to land use change. *Agriculture, ecosystems & environment.* 114 (1):69-85.

Millennium Ecosystem Assessment. 2005. *Ecosystems and human well-being: synthesis*. [Geneva, Switzerland]: World Health Organization.

Mitsuda, Yasushi, and Satoshi Ito. 2011. A review of spatial-explicit factors determining spatial distribution of land use/land-use change. *Landscape and Ecological Engineering* 7 (1):117-125.

Molnar, Jennifer L., and Ida Kubiszewski. 2012. Managing natural wealth: Research and implementation of ecosystem services in the United States and Canada. *Ecosystem Services* 2 (0):45-55.

Morgan, Jessica L., Sarah E. Gergel, and Nicholas C. Coops. 2010. Aerial Photography: A Rapidly Evolving Tool for Ecological Management. *BioScience.* 52 (1):47.

Muller, Felix, Rudolf de Groot, and Louise Willemen. 2010. Ecosystem Services at the Landscape Scale: the Need for Integrative Approaches. *Landscape Online* (23):1-11.

Naidoo, R., T. R. Malcolm, T. H. Ricketts, A. Balmford, R. E. Green, R. Costanza, B. Fisher, and B. Lehner. 2008. Global mapping of ecosystem services and conservation priorities. *Proc. Natl. Acad. Sci. U. S. A. Proceedings of the National Academy of Sciences of the United States of America* 105 (28):9495-9500.

National Atlas of the United States. *Federal Lands of the United States*. National Atlas of the United States 2005 [cited. Available from http://nationalatlas.gov/atlasftp.html.

National Park Service. 2005. Wind Cave National Park fire management plan. US Department of the Interior, National Park service, Wind Cave National Park. Hot Springs, SD.

———. 2012. National Park Service Visitor Use Statistics. Public Use Statistics Office. Denver, Colorado: U.S. Departement of the Interior.

———. *Fire management*. US Department of the Interior 2013 [cited 05/06/2013. Available from http://www.nps.gov/wica/parkmgmt/firemanagement.htm.

National Research Council. 1999. *Global environmental change : research pathways for the next decade*. Washington, D.C.: National Academy Press.

Natural Capital Project. *InVEST: Integrated Valuation of Environmental Services and Tradeoffs* 2011 [cited 1/28/13. Available from http://www.naturalcapitalproject.org/InVEST.html.

Nemec, K. T., and C. Raudsepp-Hearne. 2013. The use of geographic information systems to map and assess ecosystem services. *Biodiversity and Conservation* 22 (1):1-15.

Nicholson, Emily, Georgina M. Mace, Paul R. Armsworth, Giles Atkinson, Simon Buckle, Tom Clements, Robert M. Ewers, John E. Fa, Toby A. Gardner, James Gibbons, Richard Grenyer, Robert Metcalfe, Susana Mourato, Mirabelle Muûls, Dan Osborn, Daniel C. Reuman, Charlene Watson, and E. J. Milner-Gulland. 2009. Priority research areas for ecosystem services in a changing world. *Journal of Applied Ecology* 46:1139-1144.

O'Harra, Cleophas C. 1913. *O'Harra's handbook of the Black Hills*. Rapid City: Black Hills Handbook Co.

Olson, David M., Eric Dinerstein, Eric D. Wikramanayake, Neil D. Burgess, George V. N. Powell, Emma C. Underwood, Jennifer A. D'Amico, Illanga Itoua, Holly E. Strand, John C. Morrison, Colby J. Loucks, Thomas F. Allnutt, Taylor H. Ricketts, Yumiko Kura, John F. Lamoreux, Wesley W. Wettengel, Prashant Hedao, and Kenneth R. Kassem. 2001. Terrestrial Ecoregions of the World: A New Map of Life on Earth. *BioScience* 51 (11):933-938.

Olson, David, Marcy Moss, and Donald Arwood. 2008. South Dakota State and County Demographic Profiles. South Dakota State University, South Dakota Rural Life and Census Data Center, Dept. of Rural Sociology, College of Agricultural and Biological Sciences. Brookings, SD. http://www.sdstate.edu/soc/rlcdc/i-o/reports/upload/South-Dakota-State-and-County-Demographic-Profiles-B755.pdf

Omernik, James M. 1995. Ecoregions: A Framework for Managing Ecosystems. In *Biological Assessment and criteria: Tools for Water Resource Planning and Decision Making*, eds. D. Waynes S. and S. Thomas. Boca Raton, Florida: Lewis Publishers.

Orr, Howard K. 1975. *Watershed management in the Black Hills : the status of our knowledge*. Fort Collins, Colo.: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Dept. of Agriculture.

Parrish, J. Barry, Daryl J. Herman, Deanna J. Reyher, Station South Dakota Agricultural Experiment, Service United States. Forest, and Agriculture United States. Dept. of. 1996. *A century of change in Black Hills forest and riparian ecosystems*. Brookings, S.D.: South Dakota Agricultural Experiment Station.

Petz, Katalin, E. L. Minca, R. Leemans, and S. E. Werners. 2012. Managing the current and future supply of ecosystem services in the Hungarian and Romanian Tisza River Basin. *Reg. Environ. Change Regional Environmental Change* 12 (4):689-700.

Phillips, Claudia Goetz, and John Randolph. 1998. Has ecosystem management really changed practices on the National Forests? *Journal of Forestry* 96 (5):40-45.

Potschin, Marion. 2009. Land use and the state of the natural environment. *Land Use Policy* 26 (SUPPL. 1):S170-S177.

Potschin, Marion B., and Roy H. Haines-Young. 2011. Ecosystem services: Exploring a geographical perspective. *Progress in Physical Geography* 35 (5):575-594.

Pretty, J. N., A. D. Noble, D. Bossio, J. Dixon, R. E. Hine, F. W. Penning De Vries, and J. I. Morison. 2006. Resource-conserving agriculture increases yields in developing countries. *Environmental science & technology* 40 (4):1114-9.

PRISM Climate Group. 2012. United States Average Monthly or Annual Precipitation, 1981 - 2010, ed. T. P. C. G. a. O. S. University. Corvallis, Oregon, USA.

Progulske, Donald R., and W. H. Illingworth. 1974. *Yellow ore, Yellow Hair, yellow pine: a photographic study of a century of forest ecology*. Brookings [S.D.]: Agriculture Experiment Station, South Dakota State University.

Pugsley, Craig. 2012a. Interview by Suzanne Cotillon. Custer, SD, September 2012.

———. 2012b. Traffic count 1969-2011. Custer State Park visitor services.

Raudsepp-Hearne, C., G. D. Peterson, and E. M. Bennett. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences of the United States of America* 107 (11):5242-5247.

Raudsepp-Hearne, Ciara. 2010. Managing Ecosystem Services: tools and theory for understanding the dynamics of multiple ecosystem services on a landscape. NR66480, McGill University (Canada), Canada.

Raventon, Edward. 1994. *Island in the plains: a Black Hills natural history*. Boulder: Johnson Books.

Reyers, B., P. J. O'Farrell, D. C. le Maitre, R. M. Cowling, B. N. Egoh, and J. H. J. Vlok. 2009. Ecosystem services, land-cover change, and stakeholders: Finding a sustainable foothold for a semiarid biodiversity hotspot. *Ecol. Soc. Ecology and Society* 14 (1).

Rezatto, Helen, and Rose Mary Goodson. 1989. *Tales of the Black Hills*. Rapid City, S.D.: Fenwyn Press.

Ritchie, Martin W., Douglas A. Maguire, and Andrew Youngblood. 2005. Proceedings of the Symposium on Ponderosa Pine: Issues, Trends, and Management. Albany, CA.

Robertson, F.D. 1989. Report of the Forest Service. US Departement of Agriculture, Superintendent of Documents. Washington, D.C.

Sanders, Peggy. 2004. *The Civilian Conservation Corps: in and around the Black Hills*. Charleston, SC: Arcadia.

Schruben, Paul G., Raymond E. Arndt, Walter J. Bawiec, Philip B. King, and Helen M. Beikman. 1994. Geology of the Conterminous United States at 1:2,500,000 Scale -- A Digital Representation of the 1974 P.B. King and H.M. Beikman Map. In *U.S. Geological Survey Digital Data Series*. Reston, VA: U.S. Geological Survey.

Sedjo, Roger A. 2008. *Perspectives on sustainable resources in America*. Washington, DC: Resources for the Future.

Seppelt, Ralf, Brian Fath, Benjamin Burkhard, Judy L. Fisher, Adrienne Grêt-Regamey, Sven Lautenbach, Petina Pert, Stefan Hotes, Joachim Spangenberg, Peter H. Verburg, and Alexander P. E. Van

Oudenhoven. 2012. Form follows function? Proposing a blueprint for ecosystem service assessments based on reviews and case studies. *Ecological Indicators* 21 (0):145-154.

Shepperd, Wayne D., and Michael A. Battaglia. 2002. Ecology, silviculture, and management of Black Hills ponderosa pine Gen. Tech. Rep. RMRS-GTR-97. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Fort Collins, CO. http://www.fs.fed.us/rm/pubs/rmrs_gtr097.pdf

Smeets, Edith, and Rob Weterings. 1999. Environmental Indicators: Typology and Overview. Technical Report No. 25. Environmental European Agency. Copenhagen, Den. http://reports.eea.eu.int:80/TEC25/en/tech_25_text.pdf

Spence, Mark D. 2011. Passages through many worlds: Historic Resource Study of Wind Cave National Park. Midwest Regional Office, National Park Service. United States Department of the Interior. Omaha, NE.

Tallis, H., P. Kareiva, M. Marvier, and A. Chang. 2008. An ecosystem services framework to support both practical conservation and economic development. *Proc. Natl. Acad. Sci. U. S. A. Proceedings of the National Academy of Sciences of the United States of America* 105 (28):9457-9464.

Tengberg, Anna, Susanne Fredholm, Ingegard Eliasson, Igor Knez, Katarina Saltzman, and Ola Wetterberg. 2012. Cultural ecosystem services provided by landscapes: Assessment of heritage values and identity. *Ecosystem Services* 2 (0):14-26.

Thoreau Institute. 06/11/2013. *History of National Forest Conflicts*, 12/31/2006 2006 [cited 06/11/2013]. Available from http://www.ti.org/2chistory.html.

Troy, Austin, and Matthew A. Wilson. 2006. Mapping ecosystem services: Practical challenges and opportunities in linking GIS and value transfer. *Ecological economics : the journal of the International Society for Ecological Economics.* 60 (2):435.

U.S. Geological Survey. 2011. Protected Areas Database of the United States (PADUS) version 1.2: USGS Gap Analysis Program (GAP).

UNEP-WCMC. 2011. Developing ecosystem service indicators: Experiences and lessons learned from sub-global assessments and other initiatives. Technical Series No. 58. Secretariat of the Convention on Biological Diversity. Montreal, Canada.

UNEP World Conservation Monitoring Centre. 2011. UK national ecosystem assessment : technical report. United Nations Environment Programme World Conservation Monitoring Centre. Cambridge.

US Environmental Protection Agency. *Level IV Ecoregions of the Conterminous United States*. U.S. EPA Office of Research and Development (ORD) - National Health and Environmental Effects Research Laboratory (NHEERL) 12/22/2011 2011 [cited 10/14/2011. Available from http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm.

———. *Level III Ecoregions of South Dakota* [Vector digital data]. U.S. EPA Office of Research and Development (ORD) - National Health and Environmental Effects Research Laboratory (NHEERL) 2012 [cited 05/12/12. Available from ftp://ftp.epa.gov/wed/ecoregions/sd/sd_eco_l3.zip, http://edg.epa.gov.

USDA. 1983. Land and Resource Management Plan, Black Hills National Forest, 1 v. (various pagings). Custer, S.D.: U.S. Dept. of Agriculture, Forest Service.

———. 1996a. Final environmental impact statement Black Hills National Forest, ed. U. S. D. o. A. F. Service. Custer, S.D.: U.S. Dept. of Agriculture, Forest Service.

———. 1996b. Land and resource management plan : Black Hills National Forest, 1 v. (loose-leaf). Custer, S.D.: U.S. Dept. of Agriculture, Forest Service.

———. 2005. Black Hills National Forest Land and Resource Management Plan. Phase II Amendment. Final Environmental Impact Assessment. U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Region. Custer, S.D.

———. 2009. Large Historical Fire Polygons. Custer, SD: U.S. Dept. of Agriculture, Forest Service, Black Hills National Forest.

———. 2012a. Black Hills Regional "All Lands" Mountain Pine Beetle Accomplishments. U.S. Dept. of Agriculture, Forest Service. Washington, D.C. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5390581.pdf

———. *Forest Service. Black Hills National Forest*. U.S. Dept. of Agriculture, Forest Service 2012b [cited 09/25/12. Available from http://www.fs.usda.gov/blackhills.

———. *Natural Resource Manager - Forest Service National Visitor Use Monitoring*. U.S. Dept. of Agriculture, Forest Service 2012c [cited 10/28/12. Available from http://apps.fs.usda.gov/nrm/nvum/results/A02003.aspx/Round2.

Vandewalle, M., M.T. Sykes, P.A. Harrison, G.W. Luck, P. Berry, R. Bugter, T.P. Dawson, C.K. Feld, R. Harrington, J.R. Haslett, D. Hering, K.B. Jones, R. Jongamn, and S. Lavorel. 2009. Review paper on concepts of dynamic ecosystems and their services. The Rubicode Project Rationalising Biodiversity Conservation in Dynamic Ecosystems. http://www.rubicode.net/rubicode/RUBICODE

Vihervaara, Petteri, Mia Rönkä, and Mari Walls. 2010. Trends in Ecosystem Service Research: Early Steps and Current Drivers. *Ambio* 39 (4):314-324.

Wainger, Lisa, and Marisa Mazzotta. 2011. Realizing the Potential of Ecosystem Services: A Framework for Relating Ecological Changes to Economic Benefits. *Environmental Management* 48 (4):710-733.

Walker, Jon. 2013. Oh, what a beauty! Custer rates with best. *Argus*, 3-02-2013.

Walker, Ronald, Gary Brundige, William Hill, and Richard Sparks. 1995. Custer State Park Resource Management Plan: 1995-2010. Custer State Park. Rapid City, SD.

Wallace, K. J. 2007. Classification of ecosystem services: Problems and solutions. *Biological Conservation* 139 (3-4):235-246.

Wenning, Richard J., and Sabine E. Apitz. 2012. Ecosystem services: protecting the commons. *Integrated environmental assessment and management* 8 (3):395-6.

White Face, Charmaine *The Sacred Black Hills*. Sacred Sites International Foundation 2013 [cited 05/28/2013. Available from http://www.sacred-sites.org/preservation/endangered_black_hills.html.

Willemen, L., M. E. F. van Mensvoort, P. H. Verburg, and L. Hein. 2010. Space for people, plants, and livestock? Quantifying interactions among multiple landscape functions in a Dutch rural region. *Ecol. Indic. Ecological Indicators* 10 (1):62-73.

Willemen, Louise, Peter H. Verburg, Lars Hein, and Martinus E. F. van Mensvoort. 2008. Spatial characterization of landscape functions. *Landscape and Urban Planning* 88 (1):34-43.

Wind Cave National Park. 2011. Wind Cave National Park Foundation Statement. U.S. Department of the Interior - Wind Cave National park - Midwest Regional Office - Denver Service Center. National park Service.

Zinser, Charles I. 1995. *Outdoor recreation : United States national parks, forests, and public lands*. New York: J. Wiley.